5-1-2014

# Conch Population Demographics and Habitat Association Near Port Everglades Inlet, Florida

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Submitted to the Faculty of
Nova Southeastern University Oceanographic Center
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

May 2014

Thesis of

Charlotte A. Berry

Submitted in Partial Fulfillment of the Requirements for the Degree of

Masters of Science:

Marine Biology

Nova Southeastern University

Oceanographic Center

May 2014

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# Table of Contents

## List of Figures

## List of Tables

# Abstract

The queen conch (*Strombus gigas*) is a large marine gastropod found throughout the tropical western Atlantic including Florida. Overfishing and habitat loss have led to Caribbean-wide population declines requiring regional protections. On Florida's east coast, aggregations of conch were previously reported just south of a major shipping port near Ft. Lauderdale, an unusually high latitude for the species. This study was designed to investigate the spatial extent and population demographics of the Ft. Lauderdale conch. In summer 2012, broad-scale population surveys were conducted to document benthic cover and conch distribution and size data along 72 random transects stratified across four habitats within 2 km north and south of the inlet. Younger conch were found throughout the study area, but mostly in the colonized pavement west (CPW) habitat while old conch were found exclusively at one CPW site south of the inlet. Significantly more conch were found on the CPW south habitat than any other. Benthic cover data suggests that CPW south may have a unique community composition dominated by macroalgae and sand. In summer 2013, the CPW south habitat was surveyed using cross-shelf transects measuring aggregation extent and demographics. Five hundred and twenty five conch were found, at a density of 495 conch per hectare. Confirmed mating sightings, females with eggs, and solitary egg masses were found indicating mating in this nearshore habitat is successful. Future research should include expanded broad-scale surveys to determine if other aggregations exist and monitoring to examine the effects of environmental change on this vulnerable species.

**Keywords**: conch, population, demographics, habitat association

## Acknowledgements

This has been a great opportunity and experience for me; I thank all the people who made this possible. First I express my sincere gratitude to my major professor Dr. Brian Walker, this research project would not have been possible without him. I also thank Dr. Ron Hill, NOAA, for his guidance and expertise that helped materialize this project. I thank Dr. David Gilliam for being on my committee and assistance from the CRRAM Lab. I thank Dr. Patrick Hardigan for his time and sage statistical advice. I thank David Bryan, University of Miami, for helping collect data for the aggregation survey and providing previous data he collected in the study area. I thank my GIS and Spatial Ecology lab mates Amanda Costaregni, Ian Rodericks, and Katelyn Klug who helped gather the necessary data for this project. I thank Cody Bliss, Dana Fisco, Claire Dolphin, and Andrew Calhoun for also helping with field work. Lastly, I thank friends and family for their motivation, support, and encouragement.

# 1.0 Introduction

## 1.1 Queen Conch Fishery

The queen conch *Strombus gigas* is a large marine gastropod found throughout the tropical western Atlantic including parts of Florida. In the Caribbean it supports an important commercial fishery. Overfishing and habitat loss have led to region-wide declines in conch abundance (Berg and Olsen, 1989). Queen conch was originally harvested by local populations for centuries as subsistence food and shells for jewelry and decorations. Today, queen conch are harvested for conch meat spurred by demands from international trade and tourism. Expansion of commercial fisheries are often reported as the primary cause of overexploitation. The queen conch fishery is the second largest benthic fishery in the Caribbean, exceeded only by spiny lobster (CITES, 2003a). The annual wholesale value of the region's conch fishery is estimated at sixty million US dollars. Shells are used and traded as souvenirs for tourists, and are generally considered a by-product of the fishery rather than a primary target. In November 1992, the species was included in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). CITES is an international agreement between governments meant to ensure that international trade does not threaten survival of listed wild animal and plant species. The listing in Appendix II, requires issuance of CITES permits for all exports (CITES, 2003b). Between 1993 and 1998, the total annual landings of queen conch meat ranged from 6,500-7,300 metric tons (mt). Annual landings declined to 5,500 mt in 1999, 4,500 mt in 2000, and 3,100 mt in 2001. The largest annual landings were reported from Dominican Republic, Honduras, and Jamaica, with each country harvesting 1,000 mt (CITES, 2003b). The US is the leading importer of queen conch meat, importing 78 percent of all queen conch meat traded internationally between 1992 and 2001. France ranks second in international trade, importing 19 percent of all conch meat traded between 1992 and 2001. In September 2003, Dominican Republic and Honduras agreed to stop exporting queen conch and to include more conch population surveys and regulations of the fishery. Since the rise of commercial fisheries in the 1970's, intensive fishing pressure has led to population declines, stock collapses, and total or temporary closures of fisheries in Bermuda, Cuba, Colombia, Florida, Mexico, Netherlands Antilles, US Virgin Islands, and Venezuela (CITES, 2003a). Overfishing for domestic and international trade is the primary factor listed for population declines. Habitat degradation and the loss of shallow water seagrass meadows used as nursery habitats are also a factor of the queen conch decline (CITES, 2003b).

Florida has never had a significant queen conch fishery. A small commercial fishery existed in the Florida Keys through the mid 1900s to supply shells to the curio market, but by the 1960s there was a steady decline in abundance. In 1965, the state prohibited the harvesting of conch unless the meat was to be utilized. Queen conch meat was the highest recorded the following year for Florida but then dropped rapidly (Stevely and Warner, 1878). In 1986, a fishing moratorium banned the commercial and recreational collection of queen conch in state and adjacent federal waters (Glazer and Berg, 1994). The decline was attributed to overfishing and habitat loss from coastal development (Berg and Glazer, 1995). In Florida, the majority of queen conch have been found in the Florida Keys National Marine Sanctuary (Glazer and Kidney, 2004). Stoner (1997) states it is possible queen conch populations were historically self-sustaining in

Florida when adult populations were large. Delgado *et al.* (2008) concluded most queen conch larvae in the Florida Keys originate from the Keys and are dependent on local recruitment. Few conch larvae arrive in the Keys from upstream sources (Delgado *et al*., 2008).

When queen conch was listed in CITES Appendix II, it required countries to manage conch stocks and monitor exports to prevent extinction. Many countries developed strict regulations for harvesting conch to preserve their stocks (CITES, 2003a). Since the 1980s, several countries developed species-specific regulations and management measures for their stocks and now have implemented forms of fisheries management. The most common method for management is minimum size restrictions. These are typically shell length, lip thickness, or meat weight. The effectiveness of these size restrictions is dependent on the knowledge of the stock status, shell growth, size at maturity, and country-specific characteristics of the stock. Minimum shell length size is difficult to apply unless the shell is landed and may prove less useful for direct enforcement. A restriction requiring fishermen to take only conch with a flared lip (a sign of maturing reproductive capacity) may avoid immature conch from being harvested (Avila-Poveda and Baqueiro-Cárdenas, 2006), although a flared lip does not guarantee sexual maturity and thickness is variable and site specific (Stoner *et al*., 2012b). Minimum shell length restrictions do not prevent harvest of immature individuals unless an appropriate lip thickness size restriction is also enforced. Meat weight restrictions are only measured after the animal is dead and relationships with maturity are not well defined. They may not correlate well with lip thickness restrictions. Using a combination of lip thickness, closed fishing during the reproductive season, and control of total fishing effort may provide the optimal fishing management strategy (Stoner *et al*., 2012b).

Continuing decline in queen conch populations, habitat degradation, and lack of recovery has led to the concern. In February 2012, a petition was submitted to the Secretary of Commerce acting through the National Ocean and Atmospheric Administration and the National Marine Fisheries Service (NMFS) to list queen conch (*Strombus gigas*) under the Endangered Species Act (ESA) as "threatened" or "endangered." The petition also asks NMFS to designate critical habitat for queen conch in U.S. waters. There are four factors that threaten queen conch identified in the ESA listing petition: (1) habitat quality, which is affected by water pollution, seagrass degradation, and destruction of nursery habitat; (2) the overutilization of conch primarily for conch meat for local and international markets; (3) inadequate regulations used to manage the unsustainable harvest or eliminate illegal fishing; (4) reproduction limitation from low adult densities make conch vulnerable to human exploitation and unable to recover from population depletions. According to WildEarth Guardians, "listing the queen conch under the ESA would provide needed protection for this species by limiting or restricting U.S. take and import of the species. In addition, ESA listing would provide vital protection for critical habitat important for queen conch recovery" (Townsend, 2012).

## 1.2 Biology and Reproduction

Queen conch, are found throughout the Caribbean Sea and Gulf of Mexico ranging from Bermuda and Florida to as far south as Brazil. Conch are found in depths from <1 to 76 m (Randall, 1964) but are primarily reported at depths of 10-30 meters where there is optimum light availability for seagrass and algal growth (Sandt and Stoner, 1993). Significant populations of queen conch have been reported in deep water sites, 35-50 m, off western Puerto Rico (García-Sais et al., 2012) and 30-40 m off Martinique, FWI (Reynal et al., 2009). In heavily exploited areas, higher densities are often found in deeper depths (Ehrhardt and Valle-Equivel, 2008). Conch habitat use varies by location but preferred habitats seem to mainly consist of seagrass beds, sand, and rubble (Sandt and Stoner, 1993), although, they have also been found to inhabit coral reefs and algae plains (Davis, 2005).

Conch generally reach an age of 20-30 years old but lifespan has been estimated as much as 40 years old (Davis, 2005). Juvenile *S. gigas* growth can be seen as increases in shell length. As queen conch reach sexual maturity their shells stop growing in length and form a flared lip, continued deposition of shell material occurs on the inside of the shell and underside of the lip. Lip thickness is used as a surrogate to estimate age and can be used for comparison of population age structure. Lip thickness is defined as the area of greatest thickness approximately 2/3 of the distance posterior from the siphonal groove and 35 mm from the edge of the shell (Appeldoorn, 1988a). Shell length is defined as the length from the tip of the spire to the end of the siphonal groove in adults and juveniles (Stoner and Schwarte, 1994). Both shell length and lip thickness are used to investigate size at sexual maturity. For example, in the Bahamas, Stoner and Sandt (1992) found that juvenile queen conch only accounted for 0.9% of the total conch population at a deep water site. All other conch encountered were mature adults with fully developed shell lips. The mean shell length of adults was 219 mm and the mean lip thickness was 28 mm. More than 90% of adults had a lip thickness between 20 and 35 mm. The mean female shell length was 227 mm, slightly larger than males which had a mean of 220 mm. There was no statistical difference in lip thickness (Stoner and Sandt, 1992).

Conch are gonochoristic (individuals have separate sexes). Males and females can be visually distinguished, particularly after sexual maturity; males have a verge (penis) and females have an egg grove. Females are generally slightly larger than males (Randall 1964). Conch fertilization is internal and display a typical sex ratio of 1:1 (Stoner *et al.* 2012b). The shell lip begins to flare with sexual maturity (3.5 to 4 years) and it can reach a thickness of 17-18 mm within one year, and is one of the defining characteristics of *S. gigas* (Appeldoorn, 1988b; Stoner, 1989a).

Male and female conch may copulate with multiple individuals resulting in multiple males fertilizing egg masses from a single female (Randall, 1964). Mating occurs from March to October with most activity occurring from July to September when water temperatures are warmest (Davis, 2005) and photoperiod plays an important role in the timing of reproduction (Stoner and Sandt, 1992). Stoner and Sandt (1992) found that mating increased as a linear function of bottom water temperature and declined during and after the warmest period. There was also a strong positive correlation between the length of day and reproductive behavior (Stoner and Sandt, 1992). Females lay long strands of eggs as crescent shaped masses that contain hundreds of thousands of eggs coated with sand grains to provide camouflage from predators. Females can lay up to nine egg masses during the mating season (Davis, 2005).

After 3-5 days, the veliger larvae hatch and spend between 18 and 40 days floating and feeding on plankton before they settle on the bottom and metamorphose into the benthic form. Once in the benthic form, they graze on algae and detritus. Juveniles typically remain in seagrass beds less than 6 meters deep that provide adequate water circulation and food production. During their first year, they bury themselves in sand then emerge to graze in juvenile habitats. In their active growing stage (1-3.5 years old), the shell length will increase about 7 centimeters per year (Davis, 2005). At approximately 3.5 years conch reach terminal shell length ranging from 14-30 cm. The outer edge of the shell begins to turn outward to form a flared lip which is characteristic of the adult form. Lip thickness increases at about 5 mm per year. Lip thickness is used as a relative age index because shell length alone does not provide any real information on whether or not conch are sexually mature. However, mere presence of a lip flare may not provide adequate indication of reproduction either. Some conch are sexually mature with a lip thickness of less than 7 mm, although in most locations they reach their full reproductive potential at a larger thickness (Stoner *et al.* 2012b). As conch develop a flared lip they begin to migrate to deeper water (>6 m) to mate (Davis, 2005).

There have been some reported seasonal movements of *S. gigas*, often related to reproduction (Glazer and Kidney, 2004). Conch have been observed moving from a food rich rubble habitat to sand habitat for reproduction in the Bahamas (Stoner and Sandt, 1992). In the Turks and Caicos, conch moved seasonally, inshore in the spring and offshore, moving from seagrass to algae habitats during the winter (Hesse, 1979). In Florida, conch are most commonly observed in shallow hard bottom habitats adjacent to land and in back reefs with coarse rubble and sediment (Glazer and Berg, 1994) with the conclusion that migrations between inshore and offshore populations may be limited by a relatively large, deep (~20 m), and muddy channel known as Hawk Channel.

### 1.3 Ecology and Ecological Importance

When conch are in larval form they feed on plankton until they settle to the ocean floor.  Once demersal, they are commonly seen on seagrass beds, sand flats, gravel, coral rubble, and hard coral bottom.  Juvenile and sub-adult conch are commonly reported in coral rubble and sand flats (Randall, 1964).  Randall (1964) suggests young conch may not be able to move through dense seagrass beds.

Adult *S. gigas* are commonly found in seagrass beds containing turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*).  Seagrass beds are highly productive ecosystems that provide food, shelter, and nursery grounds for juvenile fish and invertebrates.  Seagrasses have a high level of primary production to support a diverse fish and invertebrate community (Heck *et al*., 2008).  Despite the high rates of production, the majority of seagrass inhabitants do not consume living seagrass.  Seagrass detritus and epiphytes are the base of the food-web in seagrass communities; large proportions of dietary carbon come from consumption of macroalgae and epiphytes (Stoner *et al*., 1995).  Conch primarily feed on seagrass detritus, epiphytes, and macroalgae (Stoner *et al.* 1995).  Seagrass beds may provide some shelter and camouflage from predators.  Natural predators of conch include hermit crabs, spotted eagle rays, sharks, octopi, and sea turtles (Randal, 1964).  Juveniles have higher mortality rates which decrease as they become larger (Appledoorn, 1988b).

Large invertebrates and fish have significant effects on the composition of macroalgal communities in coral reef and seagrass habitats; large aggregations of sea urchins and queen conch are known to reduce the biomass of macroalgae (Stoner *et al*., 1995). Conch affect community structure by consuming detritus, epiphytes, and macroalgae (Stoner *et al*., 1995). This can affect macrofauna community structure by competing for a common food source or reducing protective structure making certain species vulnerable to predation. Variations in the dynamics of seagrass communities may be a function of large herbivores and detritivores (Stoner *et al*., 1995). According to CITES, "The loss or substantial decreases of *S. gigas* is therefore likely to result in significant community changes and trophic cascades that will negatively affect the productivity and future recruitment of the species as well as other ecologically and economic important fisheries resources (e.g. spiny lobster *Panulirus argus*) (CITES, 2003a).

## 1.4 Previous Regional Studies

Previous studies have used a variety of methods from transects to telemetry tagging (Glazer and Berg, 1994) to examine distribution and densities of conch primarily as a means to document natural behaviors and ecological interactions or response to fishing pressure. The purpose of habitat association and distribution studies is to determine which habitats conch utilize based on age and reproductive seasonality and which habitat characteristics might be important for environmental management. Measurements of shell length and lip thickness give indications of age related differences. Glazer and Kidney (2004) found that most *S. gigas* in the Florida Keys occupied rubble, coarse sand, and rubble-coarse sand habitat of shallower water back reef zones. Adult conch preferred coarse sand and rubble-coarse sand habitats during reproductive and non-reproductive seasons (Glazer and Kidney, 2004). Conch generally avoided seagrass meadows (Glazer and Kidney, 2004). Juvenile conch in the Florida Keys region are associated with algae, bare sand, or reef flats with abundant macroalgae food source despite an abundance of available seagrass beds (Glazer and Berg, 1994). Juveniles have been found to be highly aggregated. Berg *et al*. (1992b) described this in the Florida Keys as large "herds" of juvenile queen conch.

In the Bahamas, conch distribution is influenced by water circulation, depth, food, and habitat (Stoner *et al*., 1996). Juveniles were associated with strong tidal flow and were located close to tidal channels. Juveniles were more numerous in shallow banks and reef flats that had an abundant macroalgae food source. Adults were mostly found in deeper channels and shelf regions (Stoner *et al*., 1996). Stoner and Sandt (1992) found that in the Bahamas, adult queen conch move seasonally to and from sand bottom reproductive sites. They suggested that photoperiod, temperature, wave surge, and physiological conditions of conch influenced seasonal migrations of adults (Stoner and Sandt, 1992).

Population densities and demographics vary throughout south Florida and other regions. The purpose of density studies is to obtain a better understanding of the abundance of conch and the effects of fishing or habitat change. Berg and Glazer (1991) surveyed queen conch from Miami to Boca Grande Key in 1987-1988. The area was divided into ten subsections that were mapped into 7 major benthic marine communities. Ten maps were created with a mean of 11.8 hectares surveyed on each map. During the spring surveys they found a mean of 4.82 conch per map (0.41 conch/ha) with most conch found off the lower Keys. During the summer surveys they found a mean of 9.36 conch per map (0.79 conch/ha) with most conch found off Key Biscayne. The highest mean density in the spring was 1.09 conch/ha found in limestone bedrock community. The highest mean density in the summer was 2.98 conch/ha found in the reef community (Berg and Glazer, 1991). The estimated queen conch population from Virginia Key to Boca Grande Key was 2.84 conch/ha (Berg *et al.*, 1992b). They observed 1,544 total conch with 17% being adults and 82% being juveniles. In February of 1988, they observed a large congregation of juveniles with estimated density of 610 conch/ha (Berg *et al.*, 1992b). In the Bermuda, Berg *et al.* (1992a) surveyed an area of the Bermuda platform for *Strombus gigas*. They estimated a mean density of 0.5 ± 1.6 conch/ha for the entire platform. Conch were not seen in the inshore basins. The mean density of the reef flat area alone was 0.6 ± 1.7 conch/ha. Conch were mostly found on a sand bottom with a light cover of seagrass (Berg *et al.*, 1992a).

Population density can affect the reproductive output of *Strombus gigas*, therefore high density is important. The lack of reproduction when population densities are too low is related to the lack of encounters with males and females (Stoner and Ray-Culp, 2000). This phenomenon is called the “Allee Effect” where negative per capita population growth occurs below critical population levels (Stoner and Ray-Culp, 2000). Stoner and Ray-Culp (2000) found that in the Exuma Cays, Bahamas, mating did not occur when densities fell below 56 conch/ha and spawning did not occur when densities fell below 48 conch/ha. The cross-shelf (high density aggregations and areas in between) threshold for mating was 50-70 conch/ha with population density becoming stable at 200 conch/ha (Stoner and Ray-Culp, 2000). The Florida Wildlife Conservation Commission

(FWC) states the Florida minimum threshold where reproduction does occur is at 200 adult conch/ha and at approximately 800 conch/ha, reproductive output levels off with little increase in per capita reproductive output (Glazer and Delgado, 2012).

Differences in fishing pressure can also affect the density of queen conch. These differences in density may be related to habitat choice by the animal or to the selective removal from easily fished habitats by man. Marine protected areas (MPA) and marine fishery reserves (MFR) are created to reverse the population decline of marine resources. Stoner and Ray (1996) surveyed conch in a fished area and an unfished MFR in the Exuma Cays, Bahamas. There were 31 times more conch found in the shallow (<5 m) waters of the Great Bahamas Bank in the MFR and in the deep (30 m) island shelf of the Exuma Sound where the depth is to deep for free-diving fishermen. The mean adult density was 15 times higher in the MFR. Shell length and lip thickness measurements indicated adults in the MFR migrate with age from the shallow bank nursery sites to the deeper Exuma Sound. Conch on the bank in the fished areas were harvested before they could reach deeper water for protection from fishermen. The surface currents of the Exuma Cays shelf flow to the northwest transporting late stage larvae spawned outside the reserve to the MFR (Stoner and Ray, 1996). Stoner *et al*. (2012a) found that the effectiveness of an MPA depends on the replenishment patterns of supplying recruits to surrounding fished areas and having a sustainable spawning stock inside the MPA. They surveyed conch at two locations in Exuma Cays for a 20 year comparison, Warderick Wells near the center of the Exuma Cays Land and Sea Park reserve and a fished area near Lee Stocking Island. Conch abundance and density on the shallow bank of Lee Stocking Island had no change over the 20 year period remaining low, but there was a 91 percent decline in abundance on the deeper shelf. The adult age has declined and reproductive behavior is now rare. The population is essentially being overfished. The adult abundance of Warderick Wells declined 69 percent on the shallow bank and 6 percent on the deeper island shelf. The adult age increased but juvenile abundance decreased due to low recruitment. The Exuma Cays Land and Sea Park is an important source of larvae for downstream populations from abundant mating conch on the shelf but the reserve is not self sustaining (Stoner *et al*., 2012a).

Queen conch are frequently reported to move to particular habitats during their reproductive season. Conch move from deep water feeding areas in the winter to shallow sand habitats in the summer for mating (Stoner and Sandt, 1992). Conch return to mating sites every year, although it is unknown if the same conch go back to the same sites. Sand is important for conch reproduction because it is used for egg camouflage from predators (Davis, 2005). In the Florida Keys, mating has only been observed in offshore aggregations. There has been no mating or egg mass production seen in nearshore locations with adults present. Hawk Channel, which separates the outer reefs from the Keys, is a deep water channel with soft sediment that runs parallel to the keys. Glazer and Berg (1994) hypothesized that the channel acts as a physical barrier that prevents individuals from moving between offshore and nearshore sites. It was unclear if environmental or physiological factors prevented nearshore mating (Glazer and Berg, 1994). To determine this, adult conch on nearshore habitat were translocated to offshore habitat sites. Initial histological examination confirmed conch in nearshore sites were incapable of reproducing while conch in offshore sites developed normal gonad. The gonadal conditions of females were worse than males. After three months, the gonadal conditions improved in the nearshore conch and they began to reproduce at the offshore sites. Translocation of conch between the nearshore and offshore habitat showed reproductive failure is due to an environmental condition and removing nearshore conch to suitable offshore habitat can restore reproductive viability (Delgado *et al*., 2004). Morphology, histology, neuropeptides, protein, biomarkers, gene expression, water quality, sediment organics, and tissue chemistry were analyzed between the nearshore and offshore habitats but no definitive cause of reproductive failure has been identified (Glazer *et al*., 2008). Zinc and copper were found at increased levels in nearshore conch tissues and has been known to impact reproduction in marine snails. Nearshore reproductive failure is possibly a result of exposure to heavy metals that are likely to accumulate close to shore (Spade *et al*., 2010).

### 1.5 Background for this study

The Florida Reef Tract (Figure 1) is the third largest barrier reef ecosystem in the world, spanning approximately 595 km from the Dry Tortugas to Martin County. The southern portion of the reef tract is oriented east to west mostly at the same latitude but then arcs northeast increasing in latitude. The reef tract transitions from a tropical to a temperate Holdridge Life Zone as it arcs northward (Walker and Gilliam, 2013). Estuarine biogeographic zones and spatial barriers were identified along the northern extension where the number of benthic habitats varied between 5 sub-groups (Walker and Gilliam, 2013). The northern extension of the Florida Reef Tract is a prime region to study climate change effects because increased temperatures will cause ocean acidification and coral bleaching resulting in corals and invertebrates to move northward where the reef tract transitions from a tropical to temperate environment.

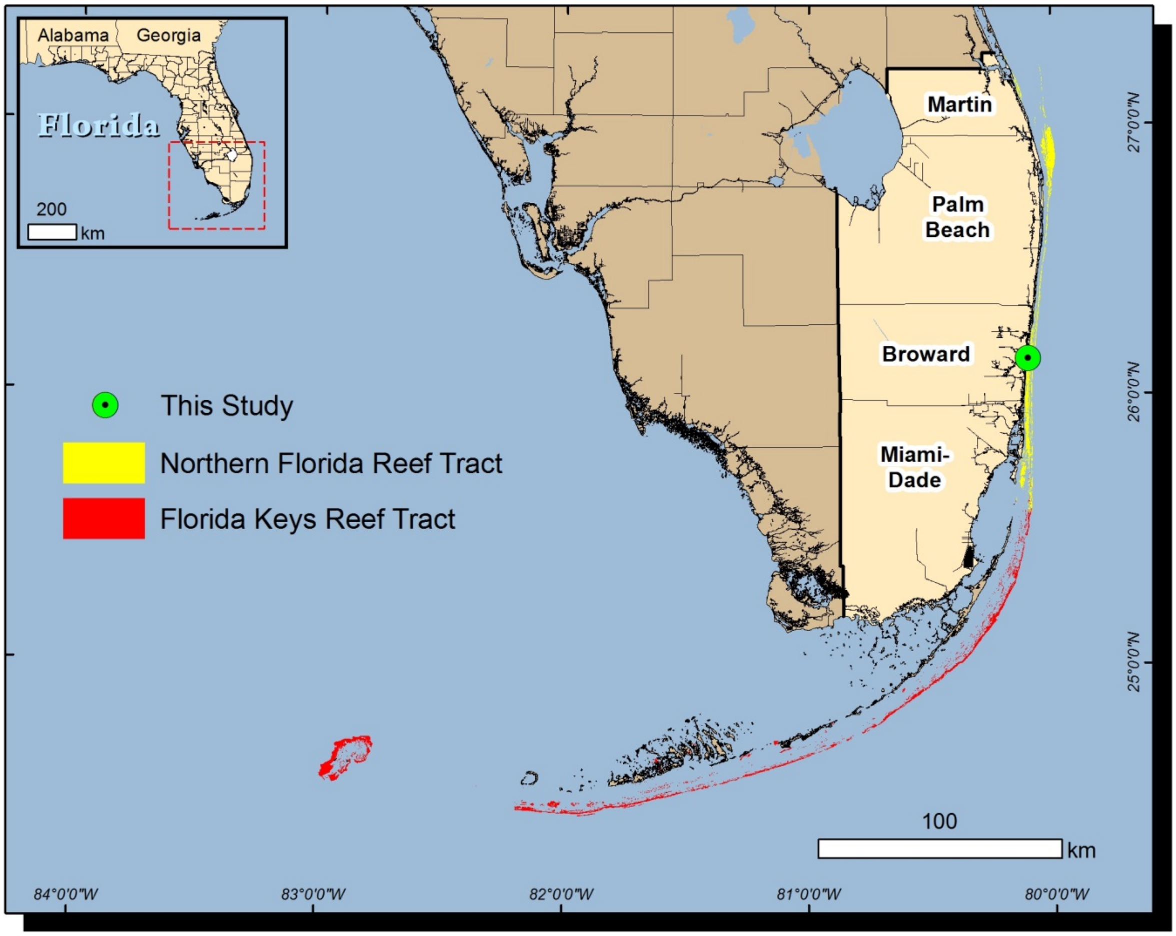


Figure 1. Map depicts the Florida Keys and the northern Florida Reef Tract. Green dot indicates this study's location.

Conch are known to occur in low numbers along the northern Florida Reef Tract up to Cape Canaveral. Aggregations of conch are found in central Broward County, Florida near Fort Lauderdale beach and adjacent to Port Everglades. These aggregations are mostly comprised of *Strombus gigas*, but others species (i.e., *Strombus costatus* and *Strombus raninus*) occur locally in low abundances as well. In 2004, Bryan and Walker (2005) identified a *S. gigas* aggregation 40 m south of the Port Everglades inlet and 300 m east of John U. Lloyd State Park. (The term aggregation in this study is defined as an area containing a higher density of conch than the surrounding areas.) They conducted three surveys in December 2004, February 2005, and May 2005 to determine the density and distribution of the aggregation. The mean aggregation density during the six months was 1,915 individuals in an area of 3.01 ha (636.2 conch/ha). Juveniles and young adults were seen south of the adult aggregation along the nearshore habitat. Several conch were seen mating and laying eggs and a few solitary egg masses were also found (Bryan and Walker 2005). This may be the first report of a reproductively active nearshore queen conch aggregation in South Florida.

In the Florida Keys, *S. gigas* mostly inhabits flat, shallow sand and hardbottom habitats. They have been found in both the nearshore habitats and on the outlier reef margin; however very little, if any, exchange of individuals between these two populations occurs (Glazer and Berg, 1994). Glazer and Berg (1994) hypothesized that a deep (~15 m) sand channel known as Hawk Channel was acting as a barrier for cross-shelf conch movements. In Southeast Florida (Martin, Palm Beach, Broward, and Miami-Dade Counties), it is speculated *S. gigas* mostly associate with nearshore environments. A large area of these shallow nearshore habitats extend northward along the coast spanning Miami-Dade and Broward counties (Walker, 2012). Along this stretch, two unnatural, deep, heavily-trafficked inlet channels have been created and maintained, Government Cut (Miami) and Port Everglades (Ft. Lauderdale). These channels have modified the natural area from a shallow (3-5 m) nearshore hardbottom habitat to a deep (14-16 m) sand channel across the nearshore shelf. This drastic change in depth and habitat may impede or disrupt conch movements.

The known conch aggregations are located just south of the Port Everglades inlet channel, however no conch surveys have been performed in surrounding habitats or in the areas north of the channel to determine if the dredged channel disrupts their distributions. Furthermore, previous studies, as mentioned, have reported that conch do not reproduce on the nearshore habitats in the Florida Keys, yet Bryan and Walker (2005) reported finding conch with eggs on the nearshore habitats south of Port Everglades. This study will help determine if conch are present on both sides of the channel, and if mating is occurring, its frequency, and possible success if eggs and small juvenile cohorts are present.

## 1.6 Objectives and Hypotheses

*S. gigas* population density and demographic data (i.e., shell length, lip thickness, sex, and abundance) are needed to understand their current status and design effective management, particularly for a species of concern. It will bring focus to an understudied, little known population and allow for appropriate management decisions to be made to help conserve these populations. It is important to understand how the modification of nearshore environments may be affecting conch movements; therefore another goal of this study was to see if Port Everglades inlet may be acting as a geographical barrier.

> $H_o$: There are no significant differences in population density, size (shell length and lip thickness), and age frequency of *S. gigas* between (1) locations (i.e., sites north or south of Port Everglades inlet), (2) habitat types, and (3) the interaction of location (north/south) and habitat (termed site-habitat).
>
> $H_1$: There are significant differences in population density, size (shell length and lip thickness), and age frequency of *S. gigas* between (1)

location (i.e., sites north or south of Port Everglades inlet), (2) by habitat types, and (3) the interaction of location (north/south) and habitat (termed site-habitat).

$H_o$: *S. gigas* populations associate with similar habitats north and south of Port Everglades inlet.

$H_1$: *S. gigas* populations do not associate with similar habitats north and south of Port Everglades inlet.

Following the initial surveys to test these hypotheses, additional surveys were conducted to add information on the aggregation of conch on the south side of the Port Everglades channel. *S. gigas* demographic information and habitat associations for the populations near Port Everglades, FL were analyzed in a way that allows comparisons with other populations found in the Florida Keys and tropical western Atlantic.

## 2.0 Methods and Materials

This study was divided into two surveys. The first survey examined the broad-scale population north and south of Port Everglades inlet to determine spatial distribution, habitat association, and density. The second survey targeted the aggregation identified south of the inlet on colonized pavement west habitat to better examine the population demographics and density.

### 2.1 Broad-scale Population Data Collection

The study area contained all nearshore habitats shallower than 10 m within 2 km North and South of Port Everglades, FL (Figures 2 and 3). Surveying was conducted from July 10, 2012 through August 21, 2012. Previous maps were used to identify existing benthic habitat types in the study area: colonized pavement, shallow ridge (R), and linear inner reef (IR) (Walker, 2012; Walker et al., 2008). Since other efforts have shown differences in benthic communities between different areas of the colonized pavement (Gilliam and Walker, 2012), colonized pavement was divided into two habitats: colonized pavement east (CPE) and colonized pavement west (CPW). The approximate mean depths between habitats were 4 m for CPW and shallow ridge, 6 m for CPE, and 9 m for inner reef. Nine sites were randomly distributed using ArcGIS in each type of benthic habitat (4) within the defined study area both north and south of Port Everglades inlet for a total of 72 sites. Two non-overlapping 30 m transects were conducted per site with all conch recorded within 2 m of each transect tape. Recorded data included the species, shell length, lip thickness, sex (when possible), the presence of eggs, behavior, and the specific micro-habitat each individual was seen on (sand, rock, algae, sponge, or coral). Shell length, the tip of the spire to the end of the siphonal groove in adults and juveniles (Stoner and Schwarte, 1994), was measured for every individual encountered. Lip thickness, the area of greatest thickness approximately 2/3 of the distance posterior from the siphonal groove and approximately 35 mm from the edge of the shell (Appeldoorn, 1988a), was only measured on individuals that had a flared lip. Sex determination was accomplished *in situ* by turning the shell aperture over and identifying a verge (male) or egg grove (female) as the animal righted itself (Figure 4).

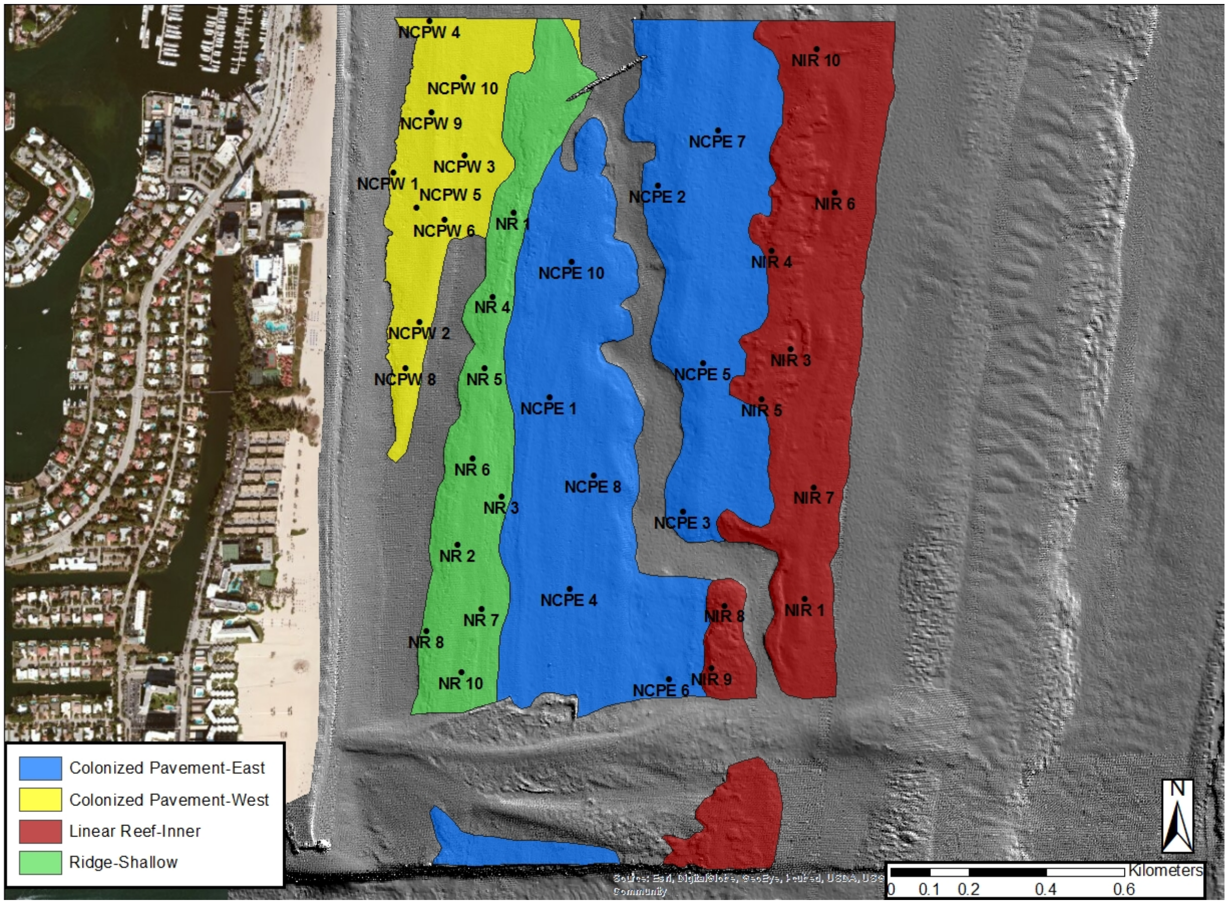

Figure 2. Study area north of Port Everglades inlet with 9 sites per each habitat type. Grey portion is a hillshaded surface layer of bathymetric lidar showing seafloor topography.

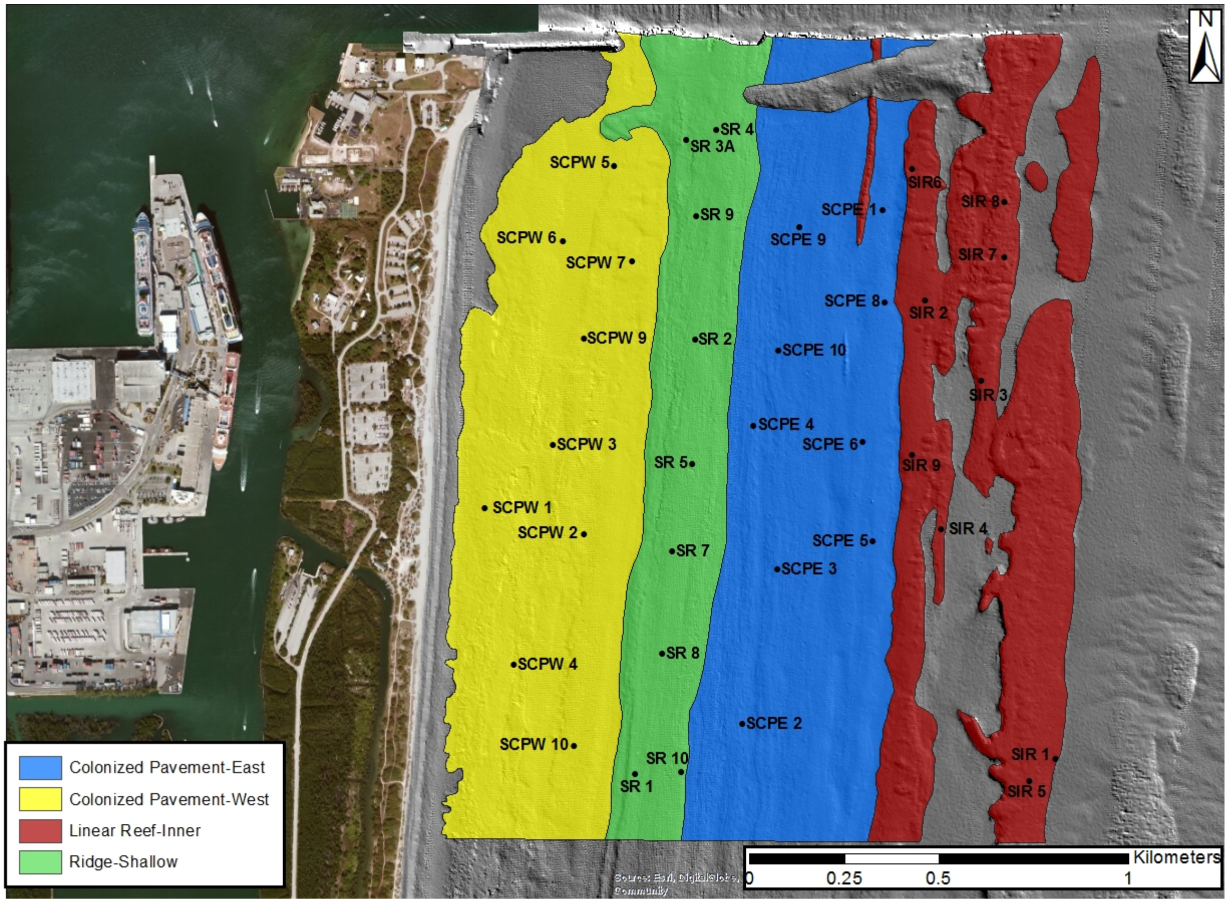

Figure 3. Study area south of Port Everglades inlet with 9 sites per each habitat type. Grey portion is a hillshaded surface layer of bathymetric lidar showing seafloor topography.

Figure 4.  Male conch "verge"(left) and female conch "egg groove" (right) used to identify sexes.

Concurrent with conch data collection, point intercept data was collected along the same transects to estimate benthic cover, composition, and rugosity.  The organism or substrate beneath every 0.25 m location along the transect was identified into main functional group categories as follows: stony coral species, gorgonian, sponge, coralline algae, macroalgae, turf algae, cyanobacteria, zoanthid, dead coral, sand, and bare substrate.  Rugosity was estimated along each transect by measuring the distance along the bottom contour and the linear distance.  The two measurements were combined to create a rugosity index for each site by dividing the contour distance by the linear distance.

Conch stop growing in shell length and the shell lip turns outward to form a flared lip that increases in thickness with age.  A flared lip indicates a minimum age of 3.5 years when the conch reaches its terminal shell length (Appledoorn, 1988a).  In some cases sexual maturity is reached with a lip thickness of <7 mm while in other areas it occurs at a larger thickness (Stoner *et al.*, 2012b).  After consulting with Gabriel Delgado at

Florida Fish and Wildlife Conservation Commission and Ronald Hill at National Marine Fisheries Service, conch were divided into three groups (Table 1) based on the presence of a flared lip and the lip thickness measurements to determine a relative age (G. Delgado, FWC, pers. comm., R. Hill, NMFS, pers. comm.).

Table 1. Age classification and lip thickness scale for each age group in this study.

| Age Group | Classification and Lip Thickness | Age |
|---|---|---|
| *No-flare* | Juvenile lip | Juvenile |
| *Small-flare* | Presence of developing or small flared lip, lip thickness 1-15 mm | Sub-Adult |
| *Large-flare* | Flared lip is large, >15 mm | Adult |

*No-flare* conch are juveniles that have no flared lip and are presumed to be the youngest conch in the population. No lip thickness measurements were taken on these conch. *Small-flare* conch are sub-adults that have a developing or small flared lip and a lip thickness measurement from 1-15 mm. Conch in this age group are in an unknown state of maturity. Some conch become sexually mature at different rates and without collecting gonad samples it is difficult to determine which individuals in this group are sexually mature. For the purpose of this study conch with a lip thickness of 1-15 mm were lumped together to form a late juvenile – early adult aged group. *Large-flare* conch are sexually mature adults that have a large flared lip with a lip thickness of >15 mm.

## 2.2 Aggregation Population Data Collection

Surveying was conducted from May 1 through June 14, 2013 south of Port Everglades inlet along John U Lloyd State Park (Figure 5). This area was identified from the broad-scale population study conducted in 2012. The survey area was approximately 778 m by 287 m targeting south CPW habitat. Field methods were based off the previous study of Bryan and Walker (2005). Eleven points were distributed along the colonized pavement west habitat type (CPW) approximately 55 m apart. From each point a 250 m transect (except transect 9 which was only 150 m) was extended approximately easterly, using a compass heading, stretching across the entire CPW habitat type to the edge of the shallow ridge habitat type (R). Due to human error and environmental conditions transects were not extended true east. All conch were recorded within 2 m on each side of the transect tape. Species, location on transect, distance from transect, shell length, lip thickness, sex (if possible), presence of eggs, and mating behavior were recorded. Start and end GPS coordinates were taken to be used to plot all transects in GIS.

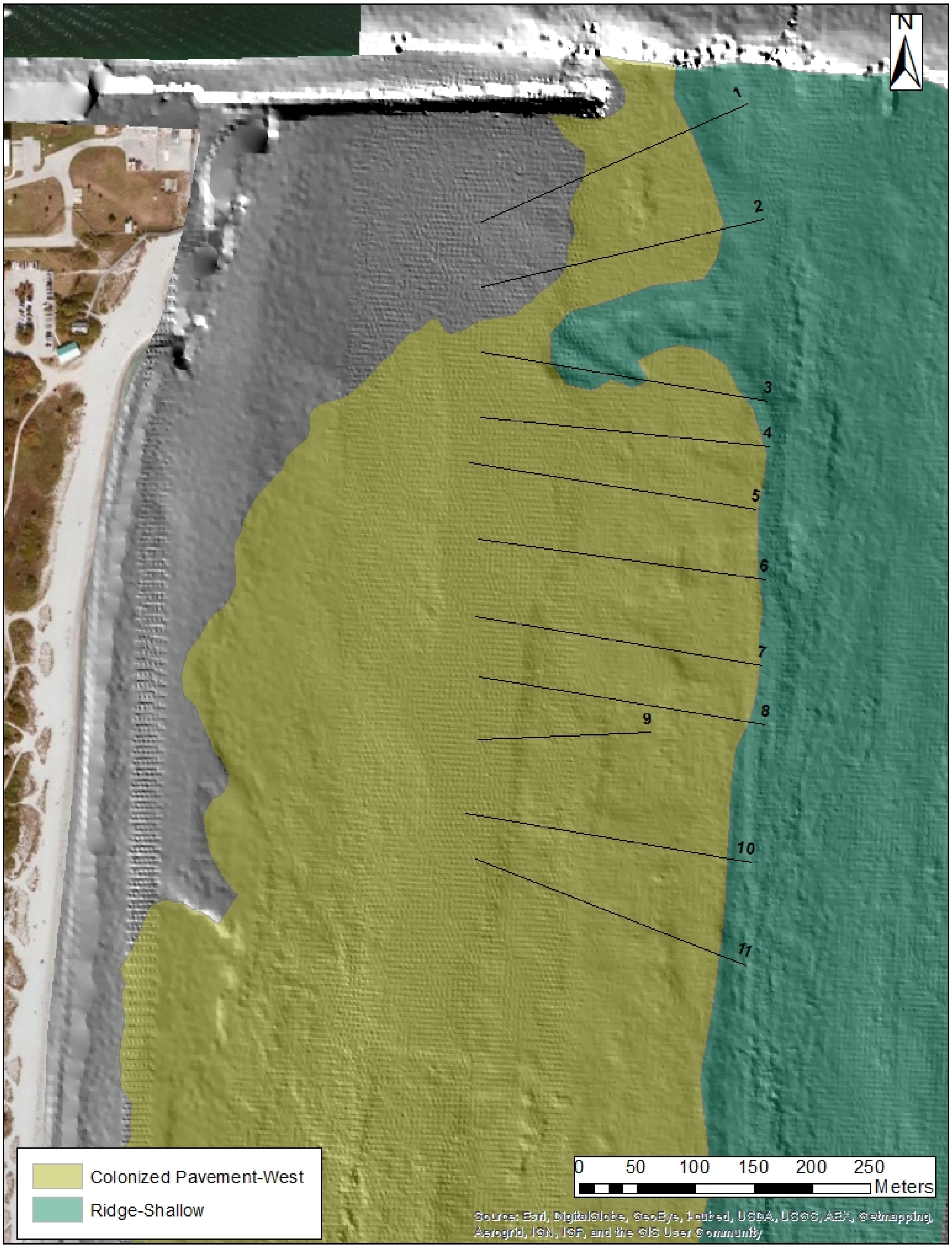


Figure 5. Aggregation population study area south of Port Everglades inlet with 11 transects. Three dimensionality is a hillshaded surface layer of bathymetric lidar showing seafloor topography.

## 2.3 Broad-scale Population Analysis Methods

Conch lip thickness, shell length, and density data were analyzed by location (north or south of the inlet), habitat type: colonized pavement west (CPW), colonized pavement east (CPE), ridge (R), and inner reef (IR), and site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR). Nonparametric ANOVA tests were run to determine significant differences between samples using JMP Pro (SAS Institute Inc.). Normality and equal variance were tested in JMP using the Shapiro-Wilk W and Bartlett's tests. A nonparametric test was used because the data were not normal. No data transformations were used because converting the data would result in disproportionate conch measurements. Using the Fit Y by X model, a nonparametric multiple comparisons Wilcoxon each pair test was used to test significance between mean density and location, habitat type, and site habitat for each age group and whole population. The same was done for the shell length and lip thickness data. Benthic cover data were analyzed using Plymouth Routines In Multivariate Ecological Research version 6 (PRIMER 6) multidimensional scaling (MDS), similarity percentage analysis (SIMPER), and one-way analysis of similarity (ANOSIM) to look at variations between sample sites that would explain distribution differences. Data were pretreated and square root transformed. Resemblance was analyzed between samples using the measure-Bray-Curtis similarity for biological data. MDS was used to plot the level of similarities between benthic cover categories and sites. Factors used in analysis were location, habitat type, and site habitat. SIMPER was used to determine percent contributions of benthic cover categories between sites. Factors used in the analyses were location, habitat type, and site habitat. The one-way ANOSIM test was used to determine statistical differences between factors: location, habitat type, and site habitat. Spatial analysis was performed using ESRI ArcGIS 10. Using the spatial analysis interpolation tool, Inverse Distance Weighted (IDW) was used for each age class to model the density and distribution of conch between sample locations. Each IDW was masked to fit the benthic habitats. This provided a visual of where queen conch densities and distributions fall within the study area. Getis-Ord GI* and Anselin Local Moran I cluster analyses were used to define hot spots and significance of clustering of conch that are different than those expected in a random distribution. Inverse Euclidian distance was selected for the spatial statistical analysis tools. Anselin Local Moran I creates a code to describe clusters of high significance (HH), clusters of low significance (LL), cluster of high significance surrounded by a cluster of low significance (HL), and cluster of low significance surrounded by a cluster of high significance (LH). Getis-Ord GI* creates a statistical z-score to identify hot spots (+2) and cold spots (-2).

## 2.4 Aggregation Population Analysis Methods

Descriptive statistics were calculated and graphed in Microsoft Excel. Conch densities for each transect and total area were calculated by dividing the number of conch by the surveyed area in $m^2$. Conch data points were created in Arc GIS 10.1 for each transect using the direction-to-distance editor tool based on the location of each conch recorded along the transect.

# 3.0 Results

## 3.1 Broad-scale Population Study

During the broad-scale population study, 122 *Strombus gigas* were recorded; 26 north of the inlet and 96 south of the inlet. Conch were not found on the north ridge habitat. Conch were most abundant south of the inlet and in colonized pavement west habitat (Figure 6). Fifty-five conch were successfully sexed, 38 female and 17 male. The data were not normally distributed and had unequal variance because the number of conch found throughout the study was not consistent between locations and habitats, thus one-way nonparametric ANOVA tests were used to determine the level of significance. The comparisons in size and age between location, habitat type, and site habitat are considered weak because of small sample sizes. The study was not designed to specifically test those factors resulting in the small sample sizes. The factors were considered and tested to investigate if there were differences in size and age between factors but small sample size may be affecting the outcomes.

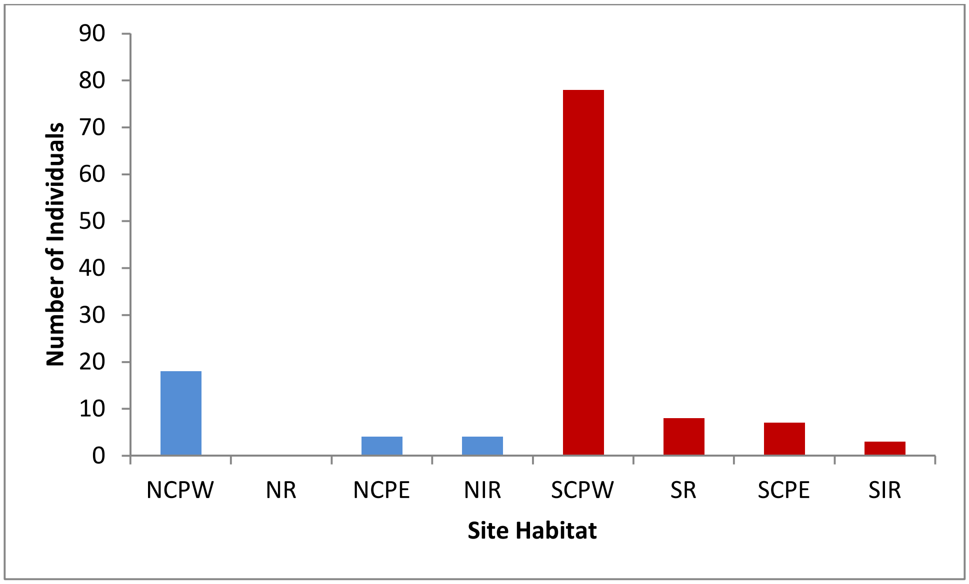

Figure 6. Conch total abundance recorded at each site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR). No conch were found on NR.

***Density***

A total of 122 conch were recorded for the entire study area and a total area of 17,280 $m^2$ was surveyed. The overall density for the broad scale (i.e., cross-shelf) population study was 70.6 conch/ha. Mean density, as the number of conch per square meter, was calculated and analyzed by location, habitat type, and site habitat to determine if there was any significant differences. Mean density south of the inlet was higher than north (Figure 7). One-way nonparametric ANOVA test showed a significant difference in density between locations (p=0.0252).

CPW habitat type had the highest density compared to the other habitat types. CPW had a mean density of 0.0222 conch/$m^2$ (±0.007 SE), R had a mean density of 0.0032 conch/$m^2$ (±0.002 SE), CPE had a mean density of 0.0025 conch/$m^2$ (±0.001 SE), and IR had a mean density of 0.0016 conch/$m^2$ (±0.001 SE) (Figure 8). One-way nonparametric ANOVA tests showed significant pair-wise differences in density between CPW and R (p=0.0086), CPW and CPE (p=0.0133), and CPW and IR (p=0.0075).

SCPW had the highest mean density of conch for all site habitats and the highest mean density south of the inlet for all habitats (Table 2, Figure 9). NCPW had the highest mean density north of the inlet. There were no conch recorded for NR. One-way nonparametric ANOVA tests showed significant differences (Table 3) in density.

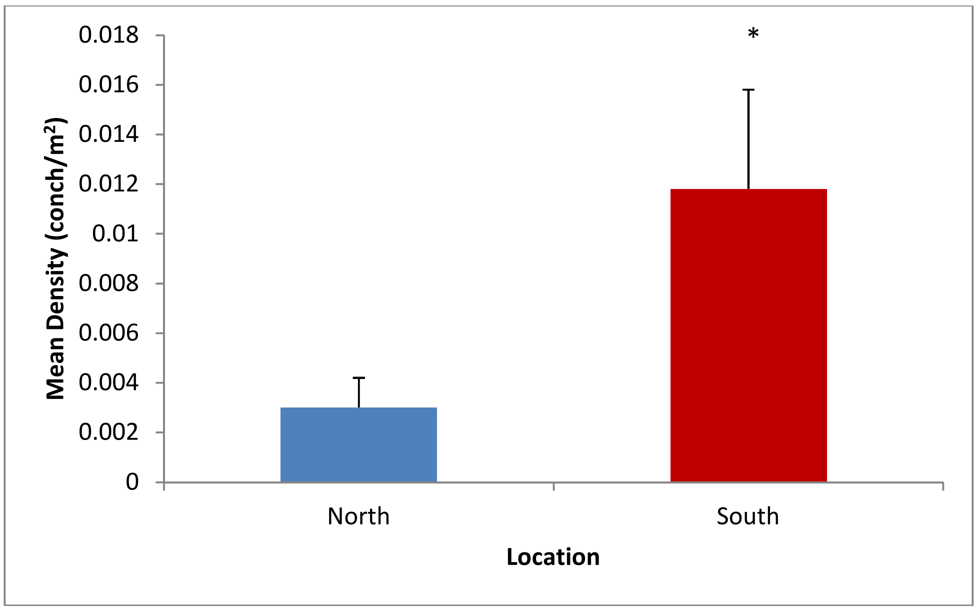


Figure 7. Mean density of *Strombus gigas* recorded during the broad-scale population study at all sites recorded north and south of Port Everglades inlet with standard error bars. One-way nonparametric ANOVA test showed a significant difference (p=0.0252) in shell length between location. * indicates significance.

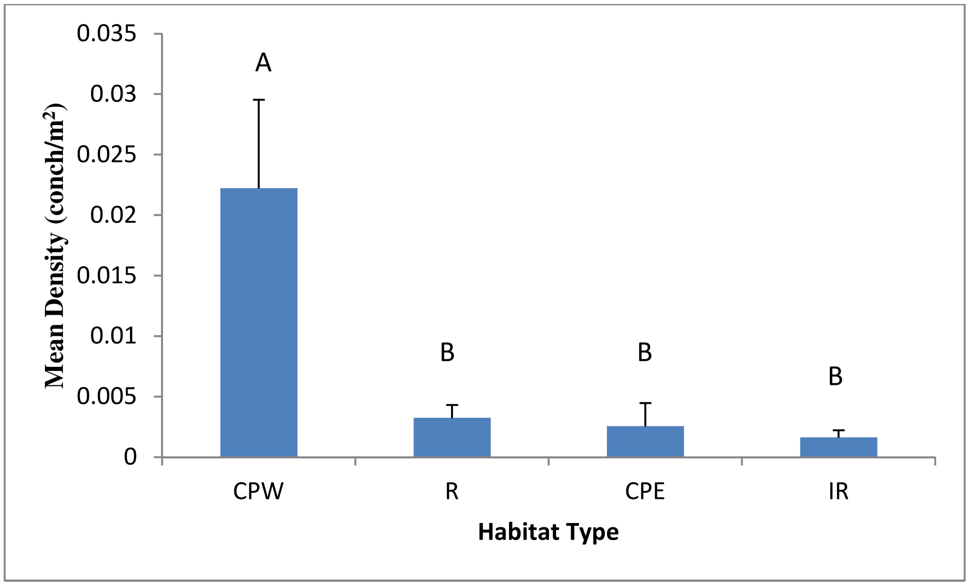

Figure 8. Mean density of *Strombus gigas* recorded during the broad-scale population study at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars. One-way nonparametric ANOVA tests showed significant difference in density between CPW and R (p=0.0086), CPW and CPE (p=0.0133), and CPW and IR (p=0.0075). There were no significant differences between CPE, R, and IR.

Table 2. Density of *Strombus gigas* recorded during the broad-scale population study at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south colonized pavement east (SCPE), south ridge (SR), and south inner reef (SIR). No conch were recorded for north ridge (NR).

| **Site Habitat** | **Mean Density (conch/m$^2$)** | **SE** |
|---|---|---|
| NCPW | 0.0083 | ±0.004 |
| NR | 0.0 | - |
| NCPE | 0.0019 | ±0.001 |
| NIR | 0.0019 | ±0.013 |
| SCPW | 0.0361 | ±0.002 |
| SR | 0.0065 | ±0.004 |
| SCPE | 0.0032 | ±0.002 |
| SIR | 0.0014 | ±0.001 |

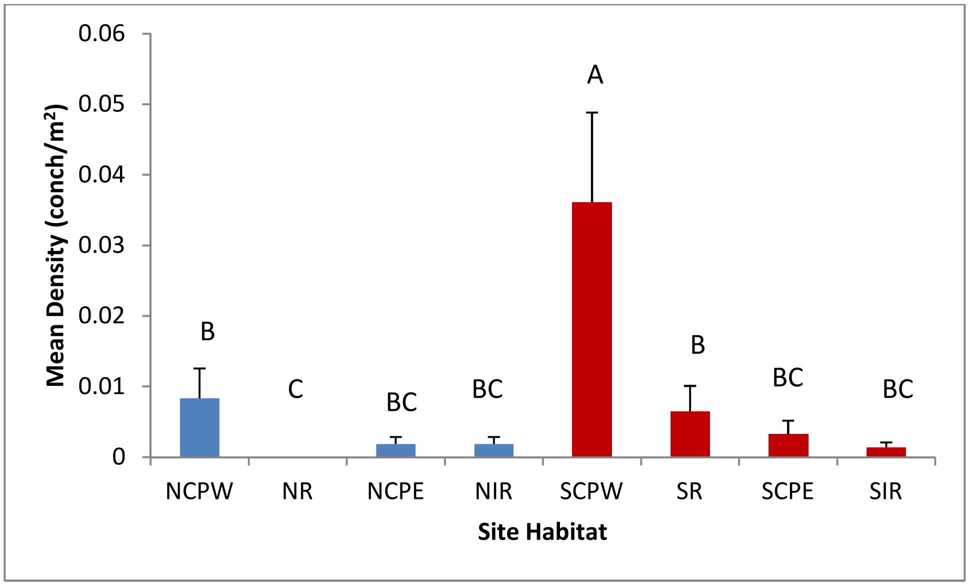

Figure 9. Mean density of *Strombus gigas* recorded during the broad-scale population study at each site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south colonized pavement east (SCPE), south ridge (SR), and south inner reef (SIR), with standard error bars. One-way nonparametric ANOVA tests showed significant differences in density (Table 3).

Table 3. One-way nonparametric ANOVA tests p values for site habitats with significant differences in density.

| Site Habitat | p Value |
|---|---|
| NCPW- NR | 0.0339 |
| NR- SR | 0.0136 |
| SCPW- NCPW | 0.0381 |
| SCPW - NR | 0.0006 |
| SCPW - NCPE | 0.0069 |
| SCPW – NIR | 0.0069 |
| SCPW – SR | 0.00340 |
| SCPW – SCPE | 0.0121 |
| SCPW – SIR | 0.0044 |

### *Shell Length*

Shell lengths ranged from 13.9-26.9 cm with a mean of 22.0 cm (±0.2 SE). Shell length measurements were analyzed for significant differences by location, habitat type, and site habitat. Mean shell length by location was similar, 22.3 cm (± 0.5 SE) north of the inlet (n=26) and 22.0 cm (±0.2 SE) south of the inlet (n=96) (Figure 10). Although the test indicated this difference was significant (p=0.0385), the result was likely confounded by the unequal total number of conch between locations and differences from these samples are judged not to be particularly valid. The mean shell lengths for habitat types were 22.1 cm (±0.2 SE) for CPW (n=96), 21.1 cm (±0.9 SE) for R (n=8), 22.1 cm (±0.8 SE) for CPE (n=11), and 22.7 cm (±1.2 SE) for IR (n=7) (Figure 11). Table 3 and Figure 12 display the mean shell lengths for site habitats. There were no conch found in NR. The significant differences occurred between NCPW and SCPW (p=0.0035), NCPW and SR (p=0.0370), SCPW and SCPE (p=0.0236), and SR and SCPE (p=0.0240).

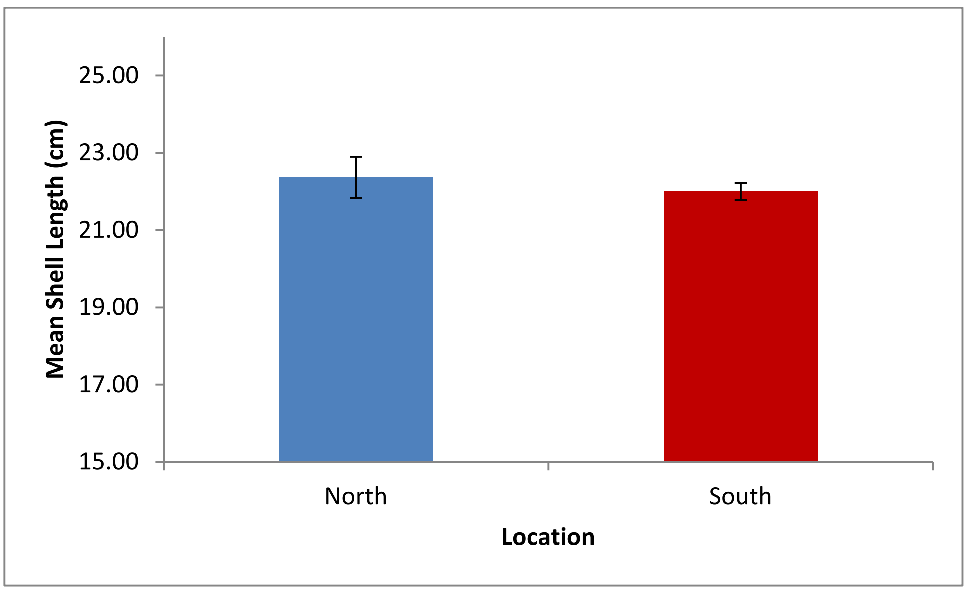


Figure 10. Mean shell length measurements of *S. gigas* recorded at all sites north and south of Port Everglades inlet with standard error bars (north n=26 and south n=96).

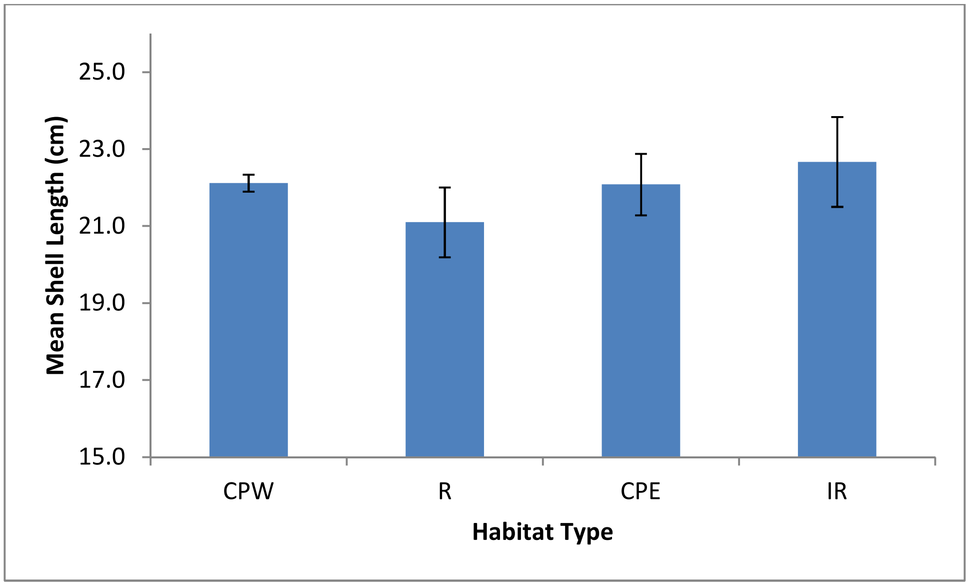

Figure 11. Mean shell length measurements of *S. gigas* recorded at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=96, R n=7, CPE n=11, IR n=8).

Table 4. Mean shell length measurements, standard error, and sample size of *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR). No conch were found in north ridge (NR).

| Site Habitat | Mean Shell Length (cm) | SE | n |
|---|---|---|---|
| NCPW | 22.9 | ±0.6 | 18 |
| NCPE | 19.8 | ±01.6 | 4 |
| NIR | 22.7 | ±1.2 | 4 |
| SCPW | 21.9 | ±0.2 | 78 |
| SR | 21.1 | ±0.9 | 8 |
| SCPE | 23.4 | ±0.3 | 7 |
| SIR | 22.7 | ±2.6 | 3 |

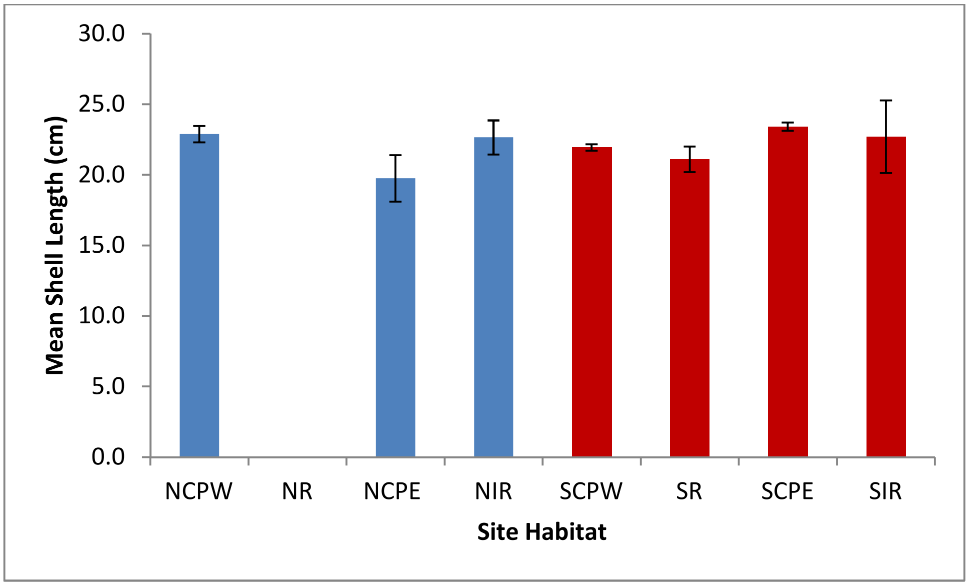

Figure 12. Mean shell length measurements of *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR), with standard error bars. No conch were found in north ridge (NR).

### *Lip Thickness*

Lip thickness was only measured on conch that had a developing or fully formed flared lip. Lip thickness was recorded from 95 *S. gigas*. Measurements ranged from 1-33 mm with a mean of 9.8 mm (±0.9 SE). Lip thickness measurements were analyzed by location, habitat type, and site habitat to determine if there was any significance between sampling sites, location, and habitats. Lip thickness ranged from 2-10 mm north of the inlet and 1-33 mm south of the inlet. The mean lip thickness by location was 5.7 mm (±0.5 SE) north of the inlet (n=16) and 10.6 mm (±1.0 SE) south of the inlet (n=79) (Figure 13), although size differences were seen the one-way nonparametric ANOVA test showed no significant difference between the lip thickness and location (p=0.3504). The mean lip thickness measurements within habitat types were 9.4 mm (±1.0 SE) for CPW (n=80), 17.5 mm (±3.3SE) for R (n=4), 10.8 mm (± 3.2 SE) for CPE (n=8), and 7.3 mm

(± 1.8 SE) for IR (n=3) (Figure 14). There was no significant difference in lip thickness between habitat types (p=0.2362). Refer to Table 5 and Figure 15 for the mean lip thickness for site habitats. There were no conch recorded for NR. The only test with a significant difference occurred between NCPW and SR (p=0.0063).

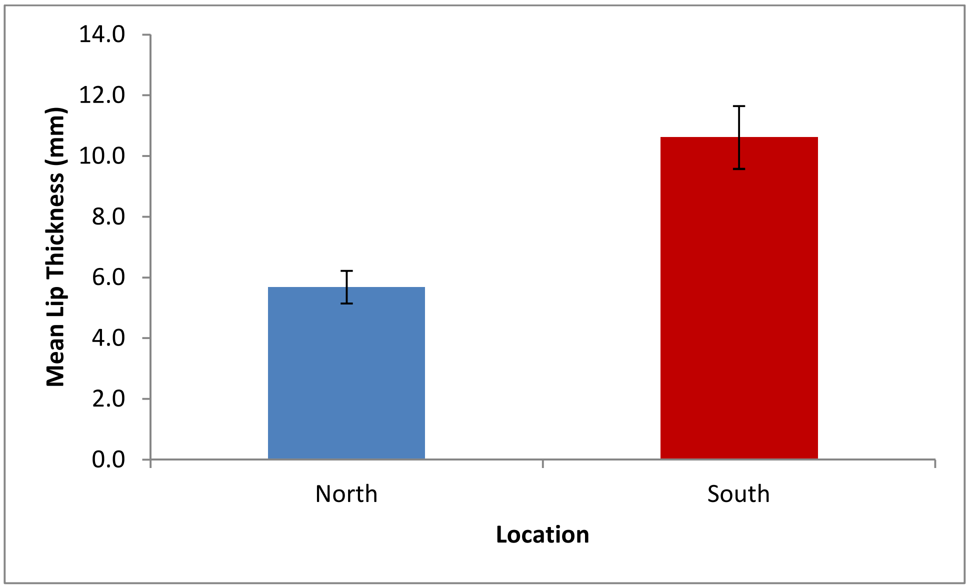


Figure 13. Mean lip thickness measurements of *S. gigas* recorded at all sites north and south of Port Everglades inlet with standard error bars (north n=16 and south n=79). One-way nonparametric ANOVA test showed no significant difference (p=0.3504) in lip thickness between locations.

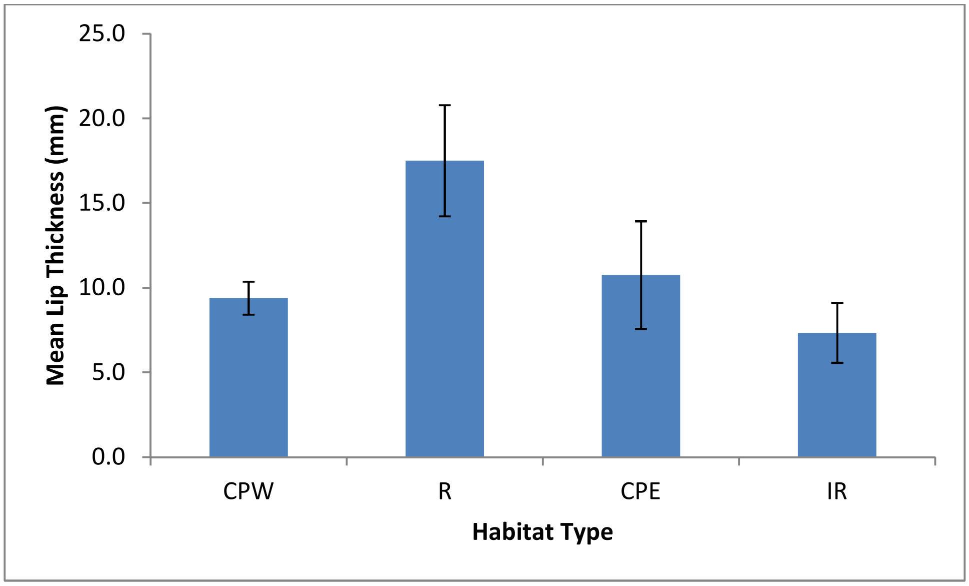

Figure14.  Mean lip thickness measurements of *S. gigas* recorded at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=80, R n=4, CPE n=8, IR n=3). One-way nonparametric ANOVA tests showed no significant differences (p=0.2362) in lip thickness between habitat type.

Table 5. Mean lip thickness measurements, standard error, and sample size of *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR).  No conch were found in north ridge (NR).

| Site Habitat | Mean Lip Thickness (mm) | SE | n |
|---|---|---|---|
| NCPW | 5.9 | ±0.6 | 14 |
| NCPE | 5.0 | | 1 |
| NIR | 4.0 | | 1 |
| SCPW | 10.0 | ±1.2 | 66 |
| SR | 17.5 | ±3.3 | 4 |
| SCPE | 11.6 | ±3.5 | 7 |
| SIR | 9.0 | ±1.0 | 2 |

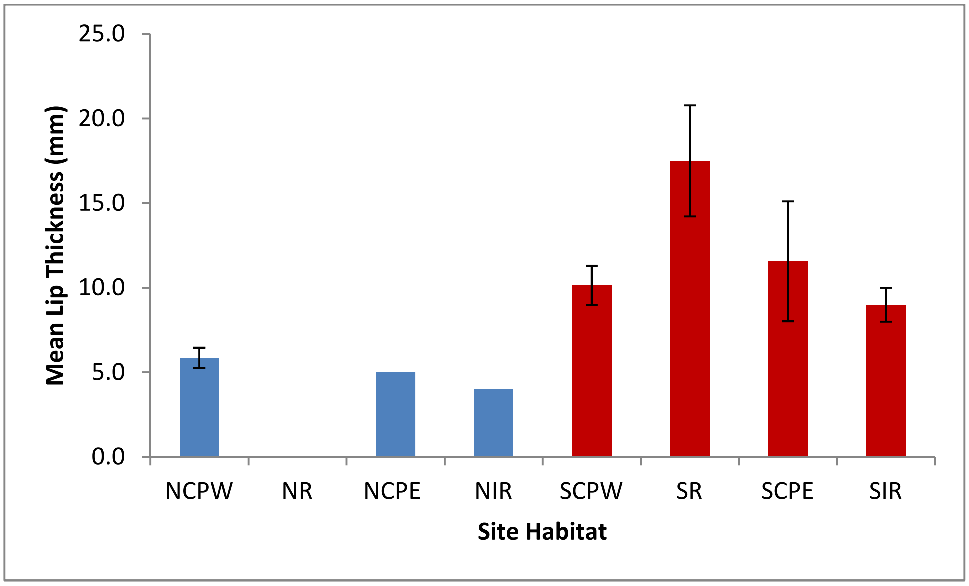

Figure 15. Mean lip thickness measurements of *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR), with standard error bars. No conch were found in north ridge (NR).

### *Age Classes*

There were 27 juvenile conch recorded during the broad-scale population study. Shell length for this group ranged from 13.9-24.2 cm with a mean of 19.7 cm (±0.5 SE). Shell length for the juvenile conch were analyzed by location (Figure 16), habitat type (Figure 17), and site habitat (Figure 18). There were no juveniles recorded for NR or SCPE. There were no significant differences in juvenile conch shell length between location (p=0.2479), habitat type (p=0.6680), or site habitat (p=0.4100).

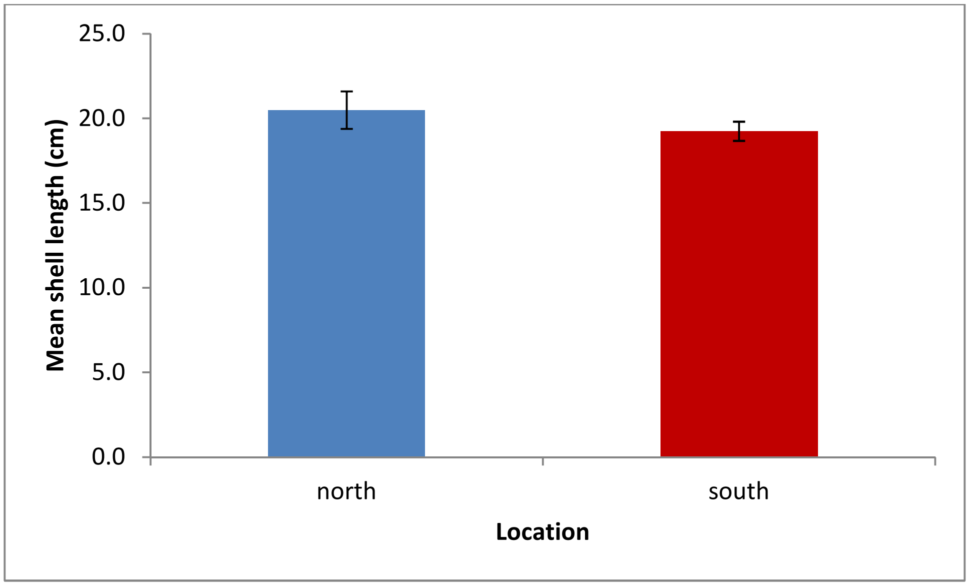

Figure 16. Mean shell length measurements of juvenile *S. gigas* recorded at all sites north and south of Port Everglades inlet with standard error bars (north n=10 and south n=17).

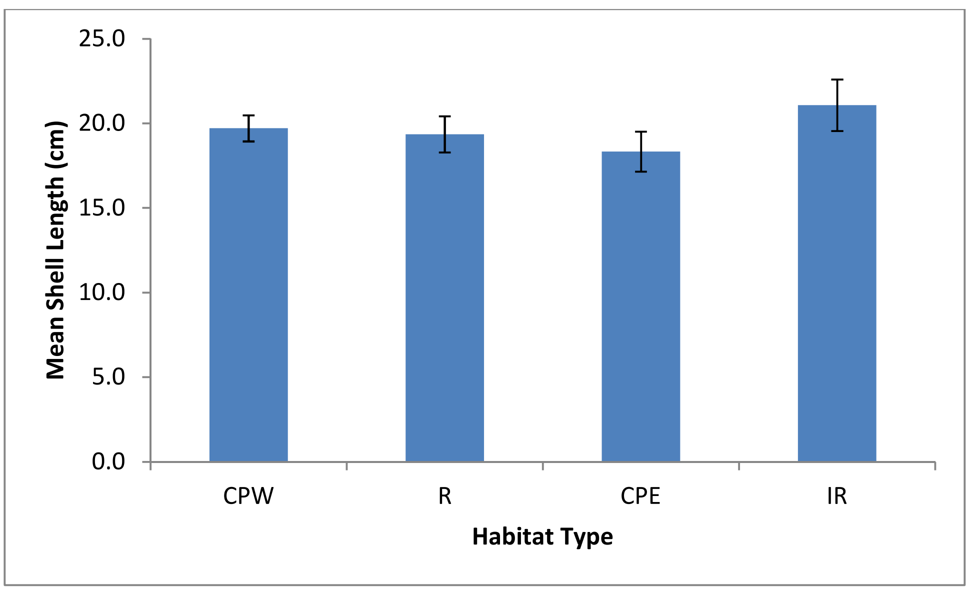

Figure 17. Mean shell length measurements of juvenile *S. gigas* recorded at each habitat type: colonized pavement west (CPW), and ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=16, R n=4, CPE n=3, IR n=4,).

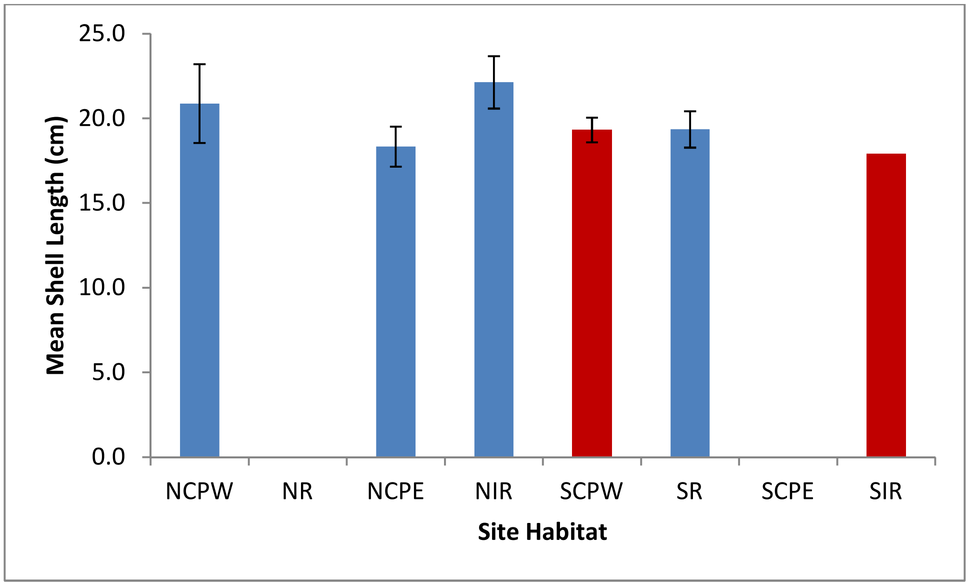

Figure 18. Mean shell length measurements of juvenile *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), and south inner reef (SIR), with stand error bars (NCPW n=4, NCPE n=3, NIR n=3, SCPW n= 12, SR n=4, SIR n= 1). No conch were found in north ridge (NR) or south colonized pavement east (SCPE).

There were 72 sub-adult conch found during the broad-scale population study. There were no sub-adults recorded for NR. Sub-adult shell length and lip thickness measurements were analyzed for significant differences by location, habitat type, and site habitat. Sub-adult shell length measurements range from 17.7-26.9 cm with a mean of 22.7 cm (±0.2 SE). The mean shell length for this age class north of the inlet are 23.5 cm (±0.3 SE) (n=16) and 22.5 cm (±0.2 SE) south of the inlet (n=56) (Figure 19). One-way nonparametric ANOVA test showed significant difference in shell length between locations (p=0.0010), the result was likely confounded by the unequal total number of conch between locations and differences from these samples are judged not to be particularly valid. The mean shell length by habitat type for this age class are 22.5 cm (±0.2 SE) for CPW (n=62), 22.8 cm for R (n=1), 23.7 cm (±0.3 SE) for CPE (n=6), and

24.8 cm (±1.0 SE) for IR (n=3) (Figure 20). One-way nonparametric ANOVA tests showed there were significant differences between the sub-adult shell length and habitat type between CPW and CPE (p=0.0244) and CPW and IR (p=0.0285). Refer to Table 6 and Figure 21 for the mean sub-adult shell length for site habitats. No conch were found in NR. One-way nonparametric ANOVA tests showed there were significant differences in sub-adult shell length by site habitat between NCPW and SCPW (p=0.0010), SCPW and SCPE (p=0.0137), and SCPW and SIR (p=0.0475) (Table 8).

Sub-adult lip thickness measurements range from 1-14.5 mm with a mean of 5.3 mm (±0.4 SE). Sub-adult lip thickness was analyzed by location (north or south) (Figure 22), habitat type (Figure 23), and site habitat (Figure 24). None were found in north ridge (NR). There were no significant differences in sub-adult lip thickness between location (p=0.02159), habitat type (p=0.2891), or site habitat (p=0.2787).

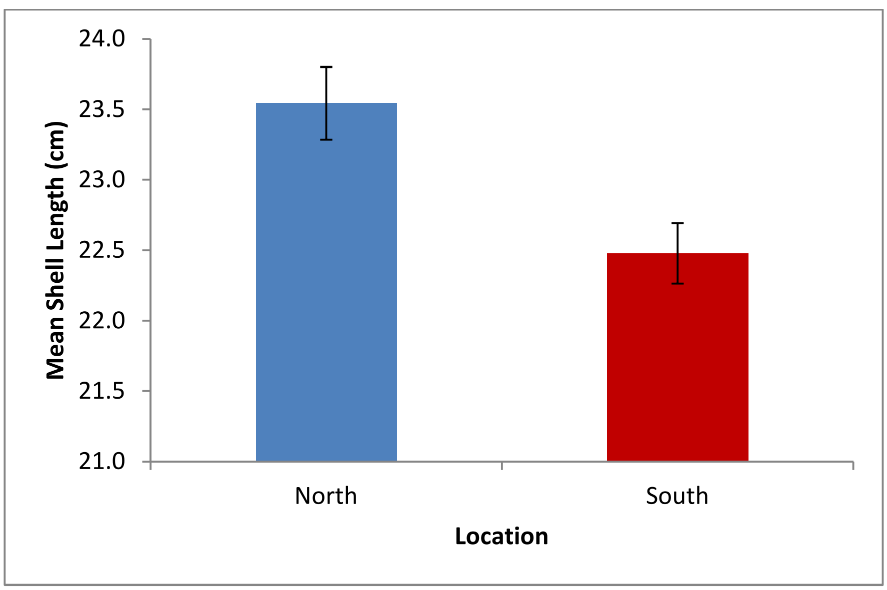


Figure 19. Mean shell length measurements of sub-adult *S. gigas* recorded at all sites north and south of Port Everglades inlet with standard error bars (north n=16 and south n=56).

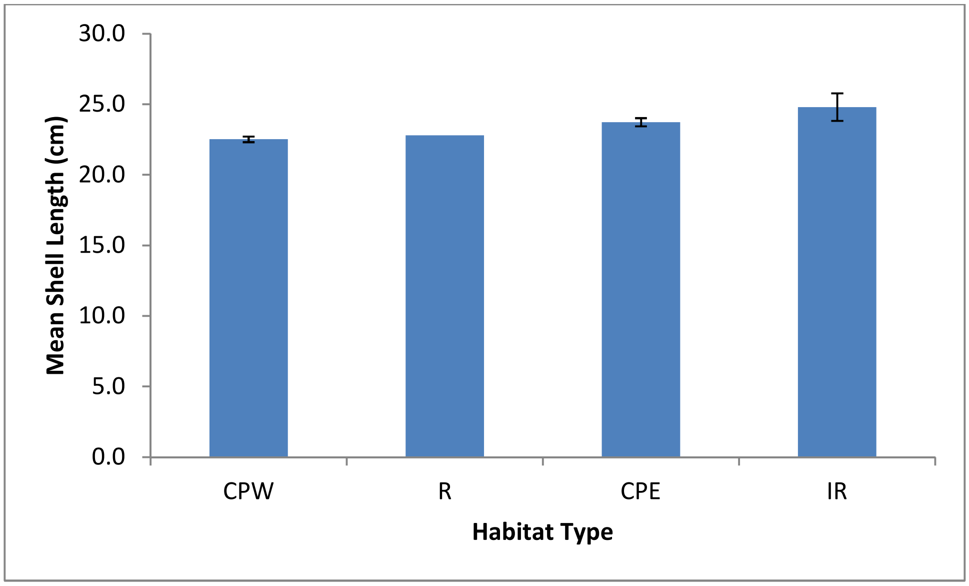

Figure 20. Mean shell length measurements of sub-adult *S. gigas* recorded at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=62, R n=1, CPE n=6, IR n=3).

Table 6. Mean shell length measurements, standard error, and sample size of sub-adult *S. gigas* recorded at each site habitat, north colonized pavement west (NCPW): north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR). No conch were found in north ridge (NR).

| Site Habitat | Mean Shell Length (cm) | SE | n |
|---|---|---|---|
| NCPW | 23.5 | ±0.3 | 14 |
| NCPE | 24.0 | | 1 |
| NIR | 24.2 | | 1 |
| SCPW | 22.2 | ±0.2 | 48 |
| SR | 22.8 | | 1 |
| SCPE | 23.7 | ±0.3 | 5 |
| SIR | 25.1 | ±1.6 | 2 |

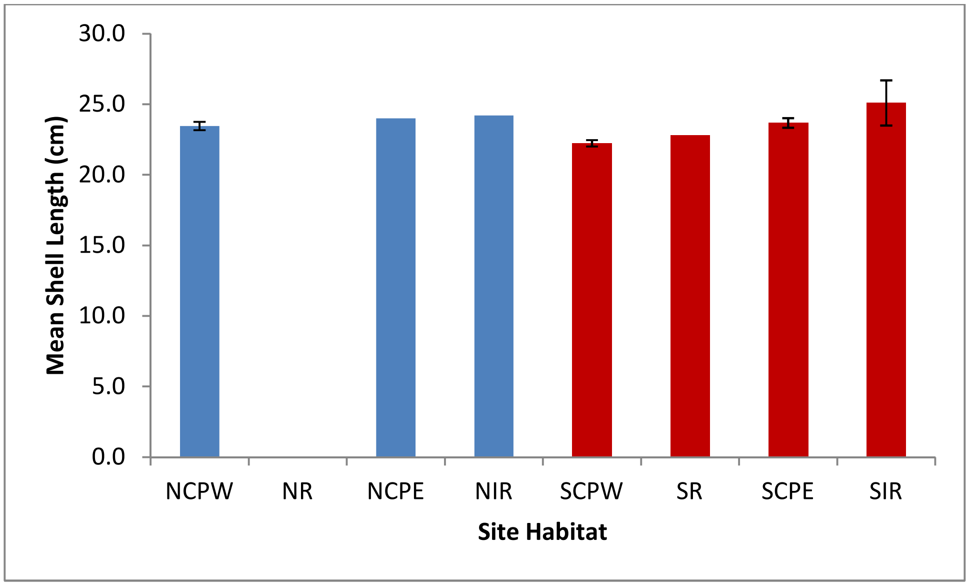


Figure 21. Mean shell length measurements of sub-adult *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR), with standard error bars. No conch were found in north ridge (NR).

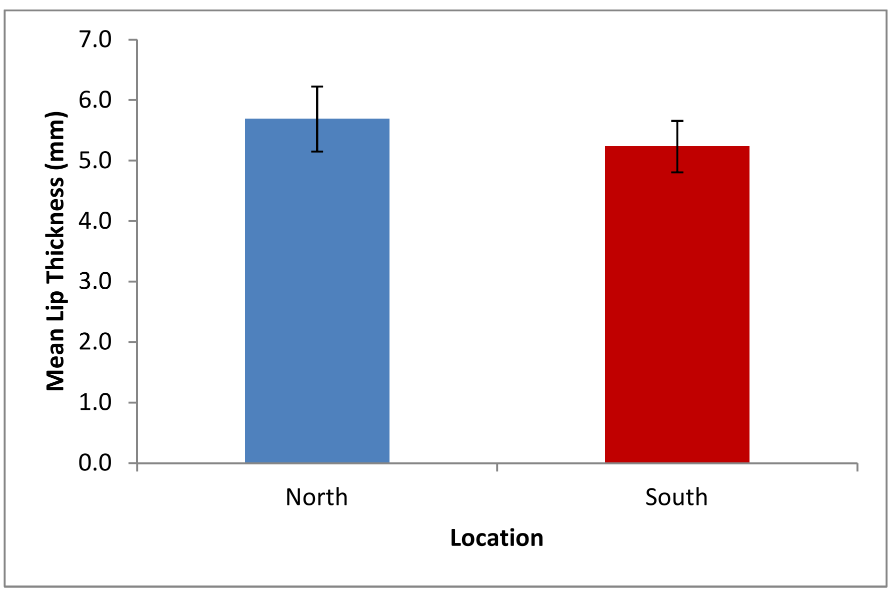


Figure 22. Mean lip thickness measurements of sub-adult *S. gigas* recorded at all sites north and south of Port Everglades inlet with standard error bars (north n=16 and south n=56).

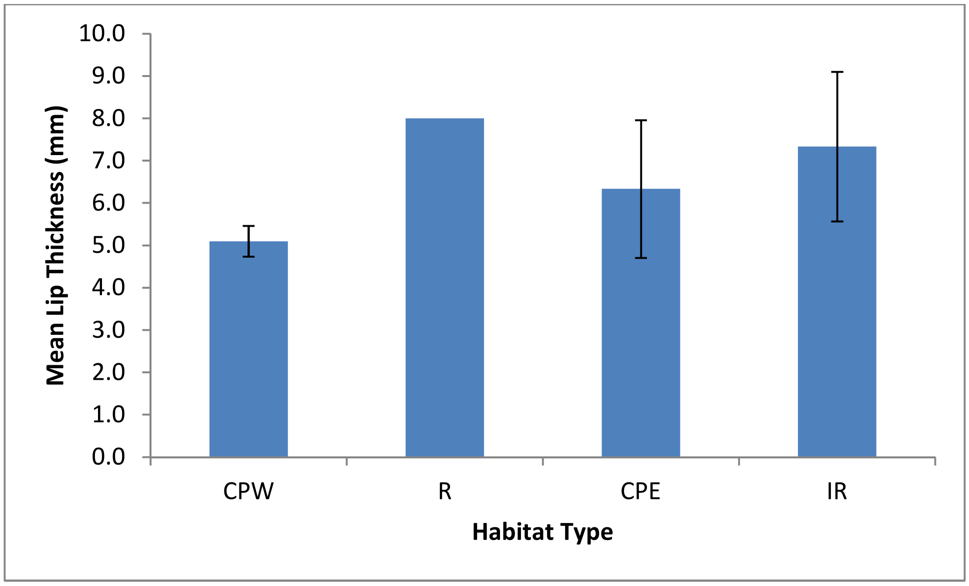


Figure 23. Mean lip thickness measurements of sub-adult *S. gigas* recorded at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=62, R n=1, CPE n=6, IR n=3).

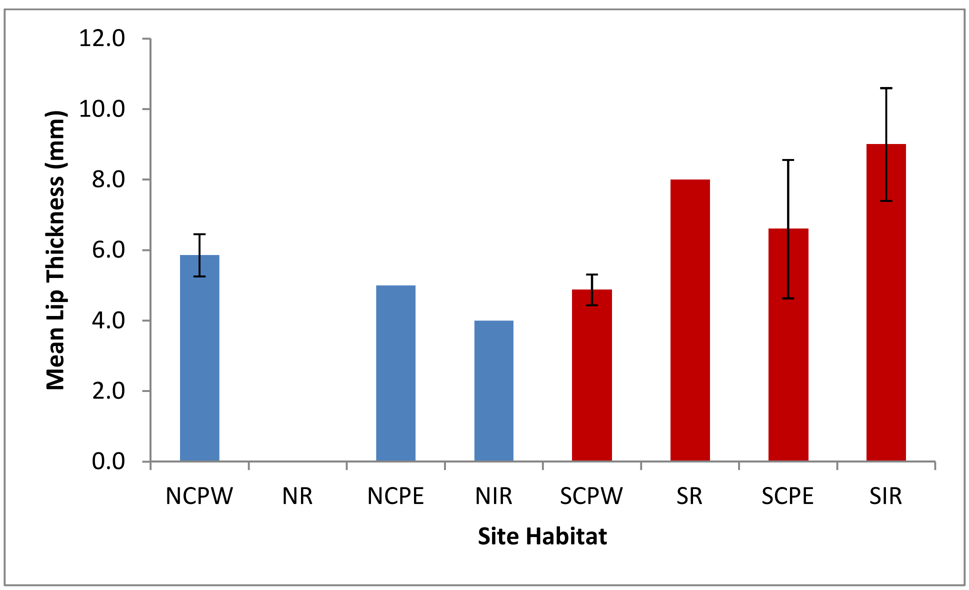


Figure 24. Mean lip thickness measurements of sub-adult *S. gigas* recorded at each site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR), with standard error bars (NCPW n=14, NCPE n=1, NIR n=1, SCPW n=48, SR n=1, SPCE n= 5, SIR n=2). No conch were found in north ridge (NR).

There were 23 adult conch recorded during the broad-scale study. Adult conch were only found south of Port Everglades inlet with majority (18) of these found at SCPW5, a single sample site. No adult conch were recorded in SIR. Shell length and lip thickness for adults were analyzed by site habitat (Figures 25 and 26). Adult conch shell length measurements ranged from 19.2-25.2 cm with a mean of 22.9 cm (±0.3 SE). There were no significant differences in adult shell length between site habitat ($p=0.9447$). Lip thickness measurements ranged from 16.0-33.0 mm with a mean of 23.7 mm (±1.0 SE). There were no significant differences in adult lip thickness between site habitat ($p=0.3881$).

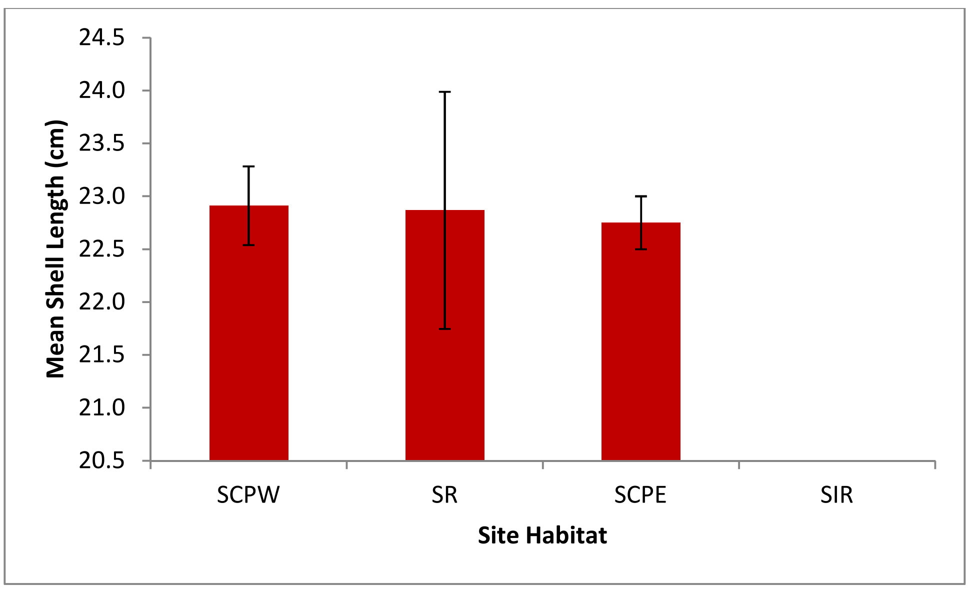


Figure 25. Mean shell length measurements of adult *S. gigas* at each site habitat south of Port Everglades inlet: south colonized pavement west (SCPW), south ridge (SR), and south colonized pavement east (SCPE), with standard error bars (SCPW n=18, SR n=3, SPCE n=2). No adult *S. gigas* were found in south inner reef (SIR).

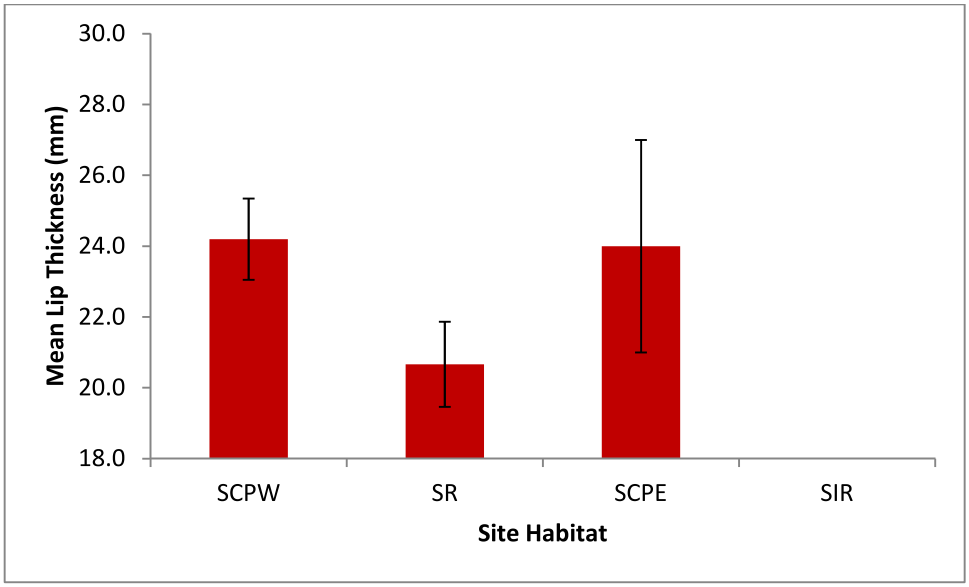

Figure 26. Mean lip thickness measurements of adult *S. gigas* at each site habitat south of Port Everglades inlet: south colonized pavement west (SCPW), south ridge (SR), and south colonized pavement east (SCPE), with standard error bars (SCPW n=18, SR n=3, SPCE n=2). No adult *S. gigas* were found in south inner reef (SIR).

### *Broad-scale Mating and Sex*

There was one sighting of adult conch mating during the broad-scale study (Figure 27) at a site south of the inlet in the colonized pavement west habitat type (SCPW5). This site contained the majority (n=18) of adult conch found throughout the study.

A total of 55 conch were successfully sexed out of the 122 conch that were recorded during the broad-scale study, 17 male and 38 female. This resulted in a sex ratio of approximately 1: 2.2. Queen conch are gonochoristic and typically have a sex ratio of 1:1 (Randall, 1964). The sex ratio was affected by the cooperation of animals being sexed because not all individuals were able to be sexed and the low abundance of conch found. A sex ratio so far from expected suggested the population was not sampled enough; therefore the aggregation survey was conducted on south colonized pavement where the highest density of conch occurred to better understand the population demographic.

Mean shell length for sub-adult and adult females and males was similar, males had a mean shell length of 22.5 cm (±0.5 SE) and females had a mean shell length of 23.2 cm (±0.2 SE). One-way non-parametric ANOVA test showed no significant difference in shell length between sex (p=0.4785). Males had a greater lip thickness than females; males had a mean lip thickness of 14.9 mm (±2.7 SE) and females had a mean lip thickness of 8.8 mm (±1.6 SE). One-way nonparametric ANOVA test showed no significant difference in lip thickness between sexes (p=0.0649).

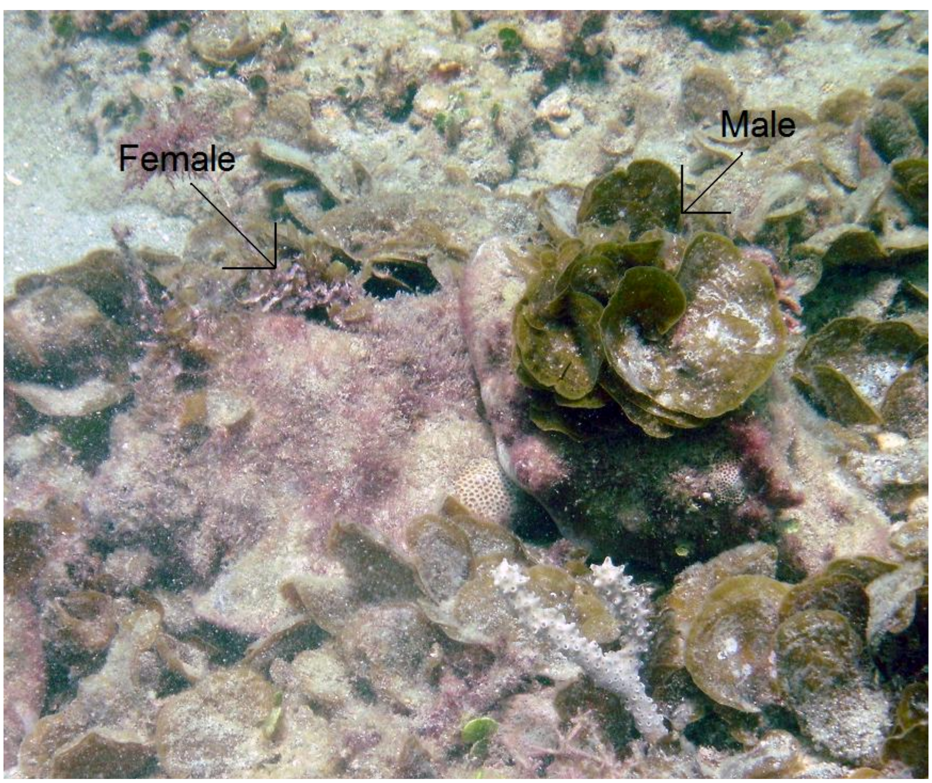

Figure 27. Mating conch south of Port Everglades inlet, FL.

### *Feeding*

There were 20 confirmed individuals seen feeding. Other individuals may have been feeding when approached but were startled and stopped feeding. Conch were seen feeding on turf algae and macroalgae epiphytes. Macroalgae samples were taken and identified as *Dictyota* sp., *Galaxaura* sp., *Lobophora variegata,* and *Halimeda discoidea*. *Lobophora variegata* was only seen and sampled at SCPW 5.

## 3.2 Benthic Cover and Habitat Association

Benthic cover and rugosity data were collected and analyzed to determine if they may be contributing to any of the observed differences in conch distribution. The three dominate benthic cover categories that compose this study area were macroalgae, turf algae, and sand (Figure 28). Zoanthids, sponges, stony corals, gorgonians, cyanobacteria, coralline algae, bare hard substrate, and dead corals made up a smaller percent of the area. The benthic cover composition was not consistent throughout each habitat type north and south of the inlet. The mean percent of benthic cover composition varied considerably between NCPW and SCPW, NCPE and SCPE, and NR and SR. The IR habitat remained similar north and south of the inlet. Benthic cover south of the inlet had a greater amount of macroalgae, coralline algae, and sand, while north of the inlet had a greater amount of turf algae (Figure 28). In general from west to east across habitat types, the benthic cover changed from mostly macroalgae, turf algae, sand, and zoanthid sp. to more gorgonians, stony corals, sponges, and turf algae. Approximately, 35 % of conch were found on sand while the remainder were found on hard bottom with various micro-habitats (algae, sponge, gorgonians, stony coral, and bare substrate) (Figure 29) indicating they may utilize hard bottom more than sandy bottom habitat.

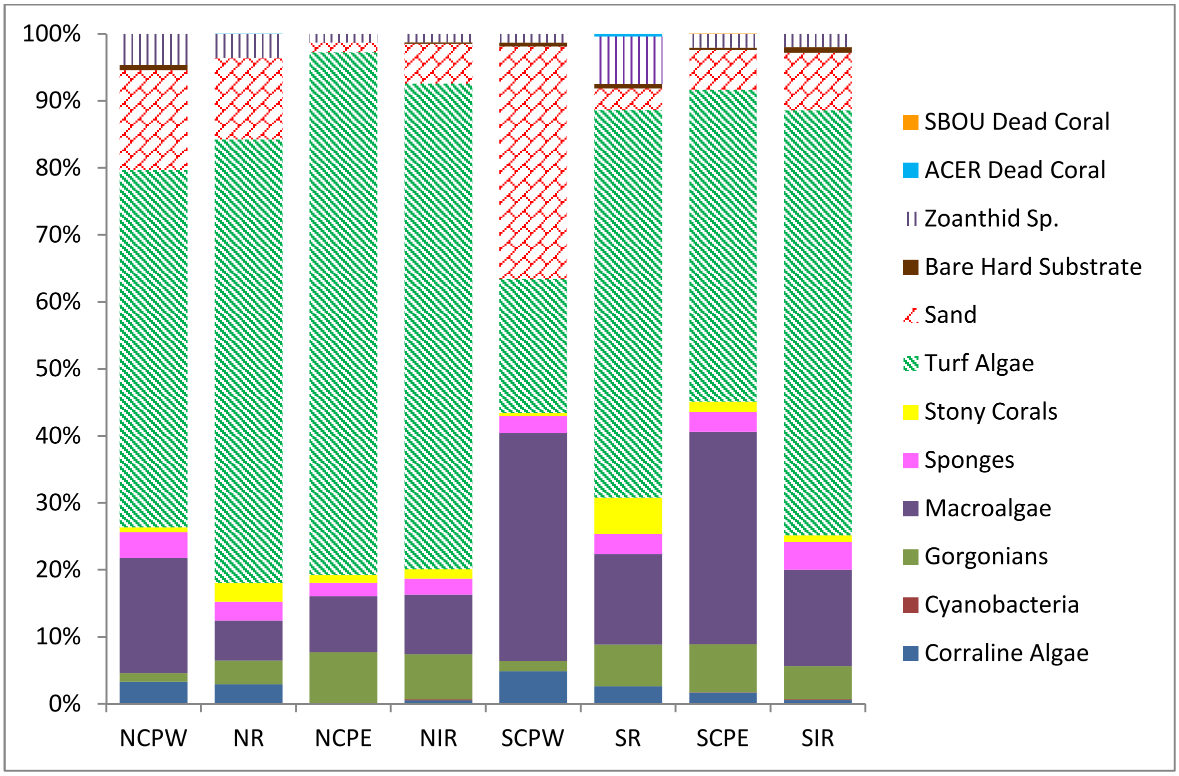


Figure 28. Mean percent of benthic cover composition at each site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SPCE), and south inner reef (SIR).

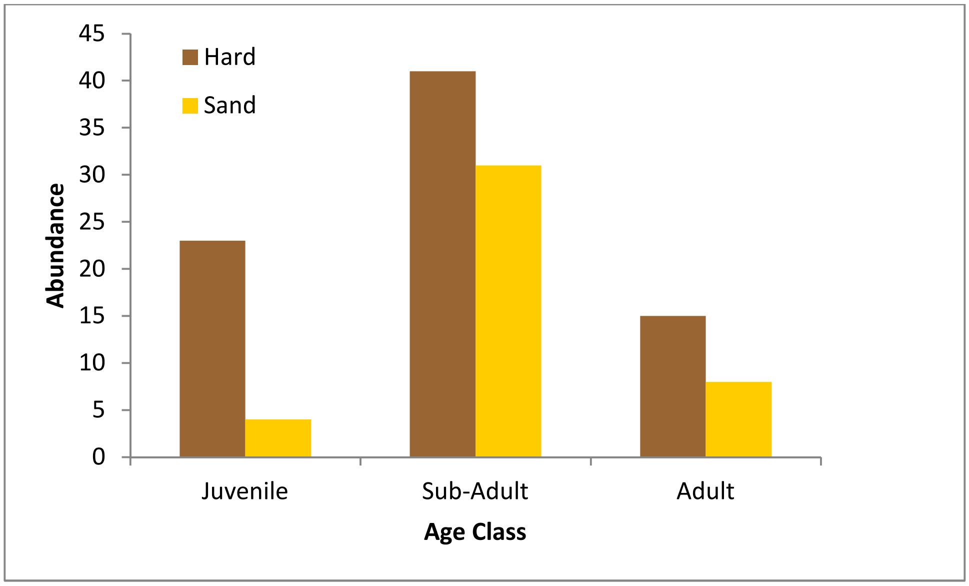

Figure 29: Abundance of conch in hard and sand bottom by age class.

Benthic cover data were square-root transformed and analyzed in PRIMER 6 for differences in benthic cover between location (north or south), habitat type, and site habitat. The cluster analysis and MDS plot showed the majority of the SCPW sites were different than the rest of the sites (Figure 30). All other site habitats cluster together. The SIMPER test showed differences in percent contribution from cover categories by location (Table 7), habitat type (Table 8), and site habitat (Table 9). Macroalgae and sand had the highest percent contribution for SCPW than all other sites. Macroalgae and sand appeared to drive the differences between sites. The ANOSIM one-way test between site habitats (Table 10) showed significant differences (significance level <5%) and medium to high R statistics (0.354–0.825) for SCPW comparisons, supporting the MDS results. SCPE sites were also significantly different from the north site habitats (NCPW, NCPE, NIR, and NR) and SR with R statistics ranging from 0.306 to 0.691. The ANOSIM one-way test also showed NCPW was significantly different from NCPE, NIR, and NR and the south ridge (SR) was significantly different from NCPE, NIR, NR, and SIR.

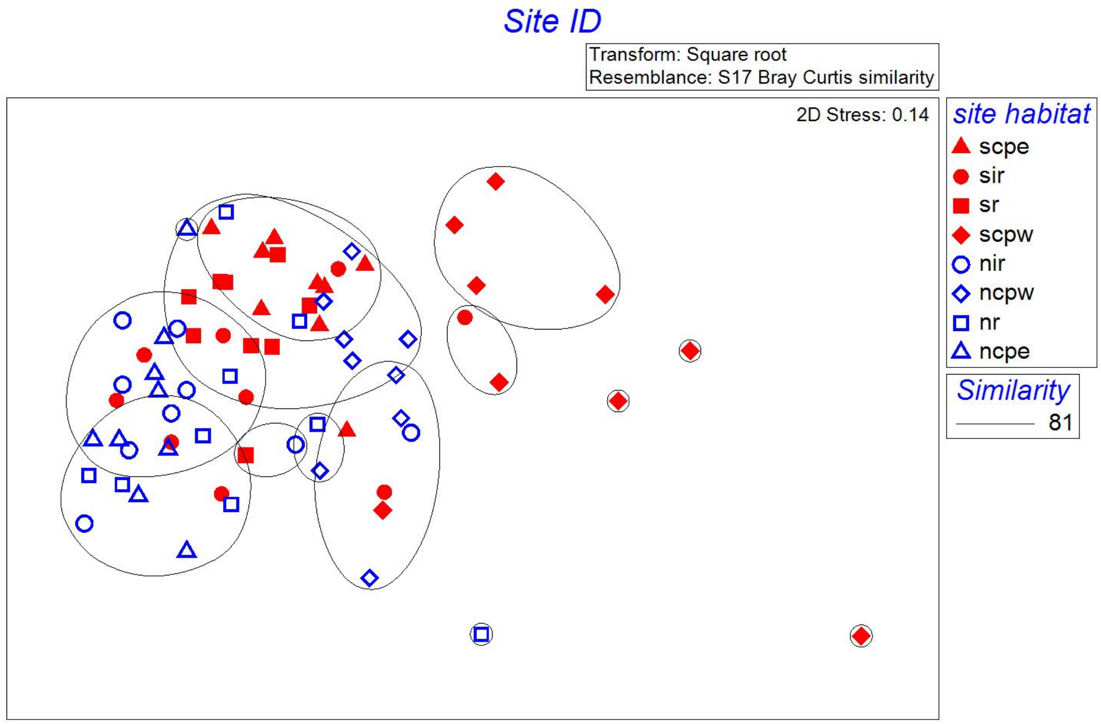


Figure 30. MDS plot for benthic cover data displayed by site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR).

Table 7. SIMPER percent contribution for transformed benthic cover data by location.

| Benthic Cover Category | North | South |
|---|---|---|
| Turf Algae | 50.90 | 34.81 |
| Macroalgae | 13.56 | 32.36 |
| Gorgonians | 9.91 | 9.09 |
| Sponges | 7.98 | 8.40 |
| Sand | 7.30 | 10.59 |
| Zoanthid sp. | 4.45 | 5.17 |
| Stony corals | 4.21 | 4.17 |
| Coralline Algae | 1.36 | 3.60 |
| Bare Substrate | 0.27 | 0.78 |
| Cyanobacteria | 0.01 | 0.02 |
| Dead ACER | 0.00 | 0.01 |

Table 8. SIMPER percent contribution for transformed benthic cover data by habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR).

| **Benthic Cover Category** | **CPW** | **R** | **CPE** | **IR** |
|---|---|---|---|---|
| Turf Algae | 28.32 | 42.49 | 45.42 | 49.60 |
| Macroalgae | 25.08 | 12.49 | 18.22 | 15.00 |
| Gorgonians | 2.91 | 10.04 | 13.92 | 12.78 |
| Sponges | 7.27 | 7.02 | 8.07 | 9.19 |
| Sand | 23.43 | 8.27 | 4.04 | 5.46 |
| Zoanthid sp. | 2.90 | 8.90 | 4.88 | 3.30 |
| Stony corals | 2.55 | 7.16 | 4.60 | 3.17 |
| Coralline Algae | 5.25 | 3.48 | 0.71 | 1.07 |
| Bare Substrate | 2.28 | 0.08 | 0.14 | 0.27 |
| Cyanobacteria | 0.00 | 0.00 | 0.00 | 0.16 |
| Dead ACER | 0.00 | 0.07 | 0.00 | 0.00 |

Table 9. SIMPER percent contribution for transformed benthic cover data by site habitat: north colonized pavement west (NCPW), north colonized pavement east (NCPE), north ridge (NR), north inner reef (NIR), south colonized pavement west (SCPW), south colonized pavement east (SCPE), south ridge (SR), and south inner reef (SIR).

| **Benthic Cover Category** | **NCPW** | **NR** | **NCPE** | **NIR** | **SCPW** | **SR** | **SCPE** | **SIR** |
|---|---|---|---|---|---|---|---|---|
| Turf Algae | 39.20 | 48.33 | 56.96 | 53.40 | 33.35 | 36.57 | 34.31 | 45.14 |
| Macroalgae | 17.46 | 10.10 | 11.91 | 13.38 | 18.56 | 15.56 | 26.78 | 16.53 |
| Gorgonians | 4.52 | 9.52 | 13.65 | 13.70 | 1.23 | 10.63 | 12.55 | 11.73 |
| Sponges | 8.54 | 6.10 | 8.01 | 7.92 | 5.12 | 7.63 | 7.33 | 10.59 |
| Sand | 15.64 | 9.25 | 2.23 | 4.69 | 31.90 | 7.43 | 5.73 | 5.96 |
| Zoanthid sp. | 4.70 | 8.49 | 3.86 | 1.32 | 1.04 | 9.21 | 5.19 | 5.74 |
| Stony corals | 2.18 | 5.73 | 3.38 | 5.22 | 2.60 | 8.36 | 5.35 | 1.39 |
| Coralline algae | 5.13 | 2.46 | 0.00 | 0.15 | 4.64 | 4.20 | 2.23 | 2.52 |
| Bare Substrate | 2.63 | 0.00 | 0.00 | 0.10 | 1.56 | 0.31 | 0.54 | 0.32 |
| Cyanobacteria | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.00 | 0.00 | 0.11 |
| Dead ACER | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 0.00 | 0.00 |

Table 10. ANOSIM one-way results for benthic cover data by site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR). Bolded groups indicate significant difference.

| Groups | R Statistic | Significance Level % |
|---|---|---|
| **SCPW, SCPE** | **0.489** | **0.1** |
| **SCPW, SIR** | **0.504** | **0.2** |
| **SCPW, SR** | **0.695** | **0.1** |
| **SCPW, NCPE** | **0.825** | **0.1** |
| **SCPW, NIR** | **0.705** | **0.2** |
| **SCPW, NR** | **0.575** | **0.1** |
| **SCPW, NCPW** | **0.354** | **0.1** |
| SCPE, SIR | 0.301 | 0.9 |
| **SCPE, SR** | **0.452** | **0.1** |
| **SCPE, NCPE** | **0.691** | **0.1** |
| **SCPE, NCPW** | **0.435** | **0.1** |
| **SCPE, NIR** | **0.548** | **0.1** |
| **SCPE, NR** | **0.469** | **0.1** |
| **SIR, SR** | **0.306** | **0.1** |
| SIR, NCPW | 0.313 | 0.5 |
| SIR, NCPE | 0.112 | 6.4 |
| SIR, NIR | 0.012 | 35.4 |
| SIR, NR | 0.049 | 20.1 |
| **SR, NCPE** | **0.65** | **0.1** |
| **SR, NIR** | **0.418** | **0.1** |
| **SR, NR** | **0.208** | **1.1** |
| **NCPW, NCPE** | **0.802** | **0.1** |
| **NCPW,NIR** | **0.591** | **0.1** |
| **NCPW, NR** | **0.308** | **0.1** |
| NCPE, NIR | -0.037 | 68.7 |
| NCPE, NR | 0.201 | 2 |
| NIR, NR | 0.096 | 10.4 |

### *Rugosity*

Rugosity was analyzed by location (north or south), habitat type, and site habitat. Mean rugosity index north of Port Everglades inlet was slightly smaller (1.0232 ±0.004 SE) (n=35) than south of the inlet (1.0296 ±0.002 SE) (n=36) (Figure 31). One-way nonparametric ANOVA test showed a significant difference in rugosity index between locations (p=0.0033). The mean rugosity index by habitat type was 1.0234 (±0.004 SE) for CPW (n=18), 1.0370 (±0.006 SE) for R (n=18), 1.0241 (±0.003 SE) for CPE (n=17), and 1.0212 (±0.003 SE) for IR (n=18) (Figure 32). One-way ANOVA test showed significant difference in rugosity index between habitat types R and IR (p=0.0130). The mean rugosity index by site habitat was 1.0196 (±0.004 SE) for NCPW (n=9), 1.0369 (±0.012 SE) for NR (n=9), 1.0182 (±0.003 SE) for NCPE (n=8), 1.0177 (±0.004 SDE) for NIR (n=9), 1.0272 (±0.006 SE) for SCPW (n=9), 1.0371 (±0.003 SE) for SR (n=9), 1.0294 (±0.004 SE) for SCPE (n=9), and 1.0247 (±0.004 SE) for SIR (n=9) (Figure 33). One-way ANOVA test showed significant difference in rugosity index between site habitats NCPW and SR (p=0.0151), NCPE and SR (p=0.0020), NCPE and SCPE (p=0.0423), NIR and SR (p=0.0047), NIR and SCPE (p=0.0423), and SR and SIR (p=0.0217) (Table 13). Although significant differences in rugosity were found, the differences were small and did not affect the outcomes.

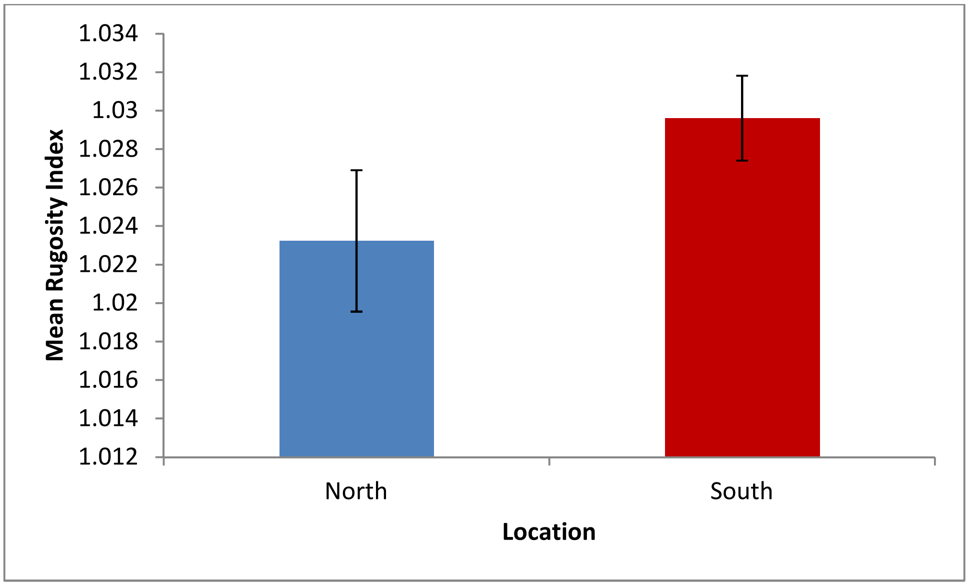

Figure 31. Mean rugosity index calculated at all sites north and south of Port Everglades inlet with standard error bars (north n=35, south n=36).

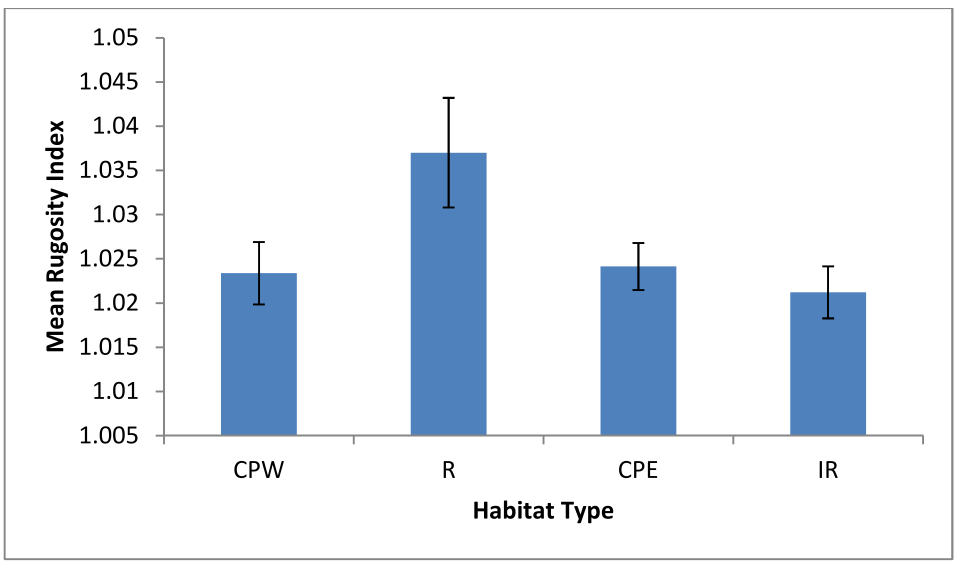

Figure 32. Mean rugosity index calculated at each habitat type: colonized pavement west (CPW), ridge (R), colonized pavement east (CPE), and inner reef (IR), with standard error bars (CPW n=18, R n=18, CPE n=17, IR n=18).

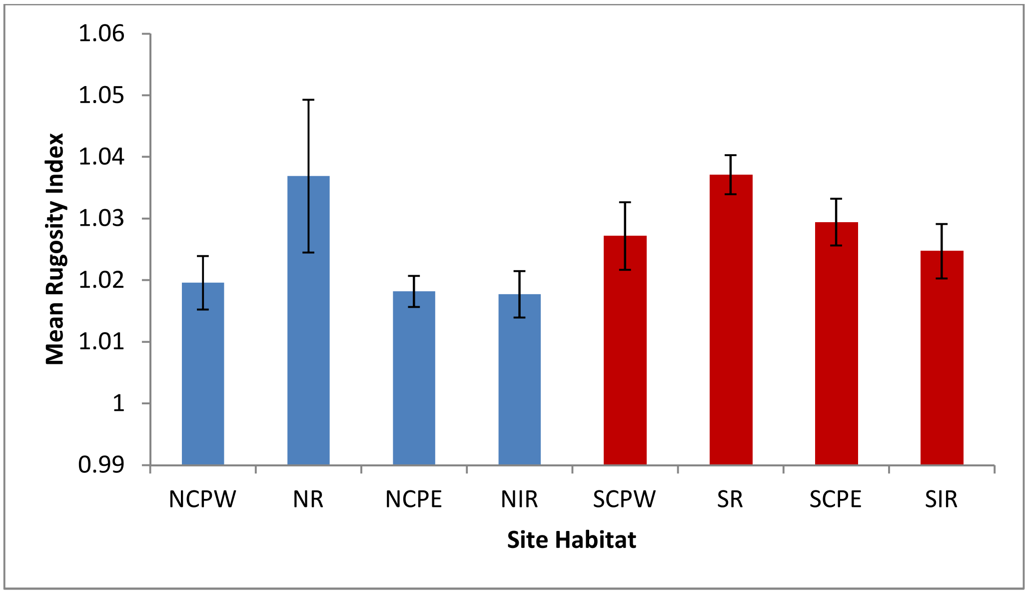


Figure 33. Mean rugosity index calculated at each site habitat: north colonized pavement west (NCPW), north ridge (NR), north colonized pavement east (NCPE), north inner reef (NIR), south colonized pavement west (SCPW), south ridge (SR), south colonized pavement east (SCPE), and south inner reef (SIR), with standard error bars (NCPW n=9, NR n=9, NCPE n=8, NIR n=9, SCPW n=9, SR n=9, SCPE n=9, SIR n=9).

### *Spatial analyses*

Conch abundance data were modeled spatially in ArcGIS to examine the distribution (Figures 34-37). Conch were found throughout the study area, but the majority were located south of Port Everglades inlet in CPW habitat. All conch were generally distributed nearshore along CPW habitat, with lower abundance in CPE and R habitats (Figure 34). Spatial analysis of abundance varied between the different age classes. Juvenile conch were found throughout all habitats, but mostly at the CPW sites (Figure 35). Sub-adult conch were primarily found in CPW habitats with higher abundance in SCPW (Figure 36). SCPW5 was a unique site where the majority of adult conch were located (Figure 37). This site was characterized by a specific type of macroalgae (*Lobophora variegata)* that was not seen at any other site.

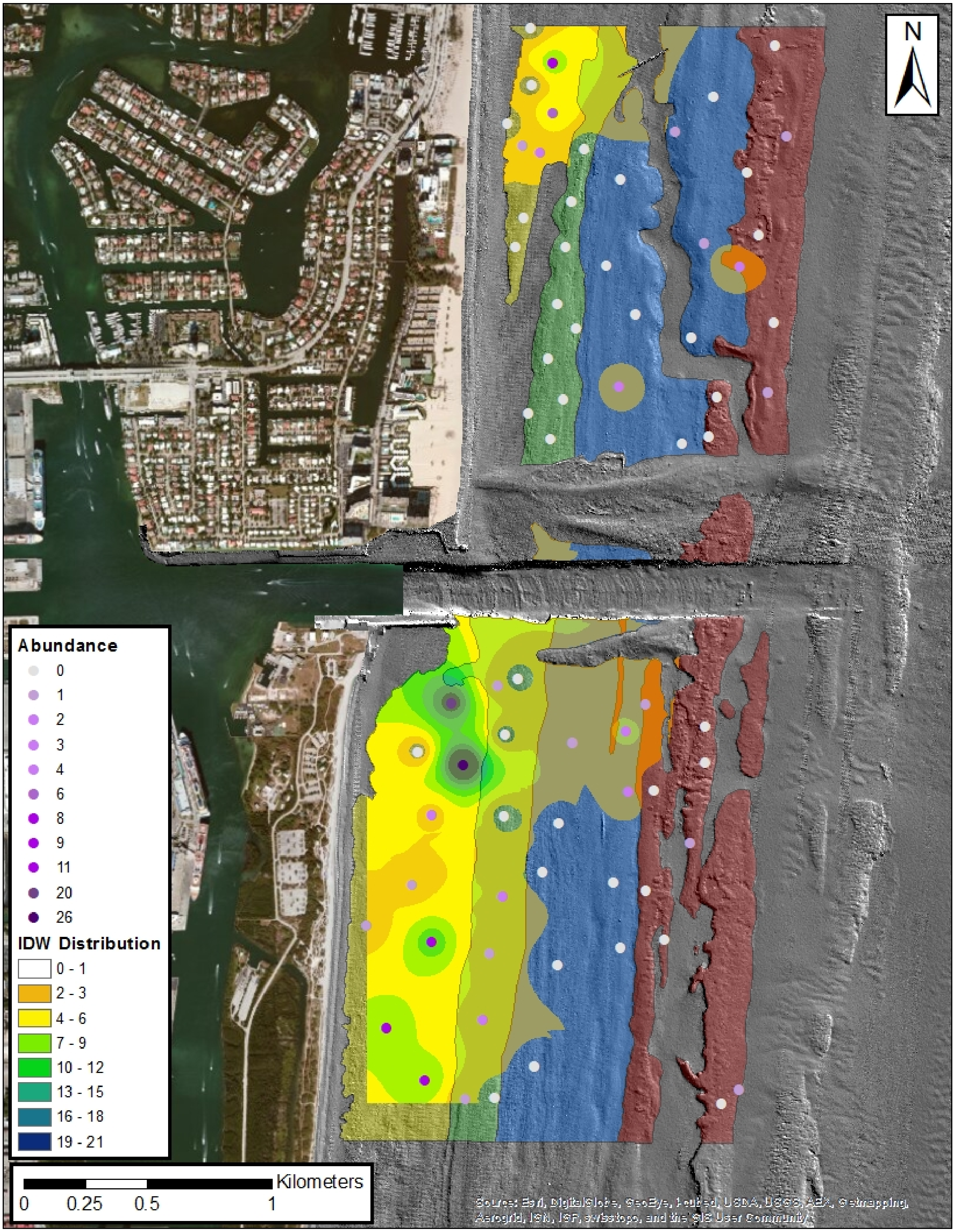


Figure 34. Interpolated distance weighted (IDW) distribution between sites and actual abundance values at each site of all conch.

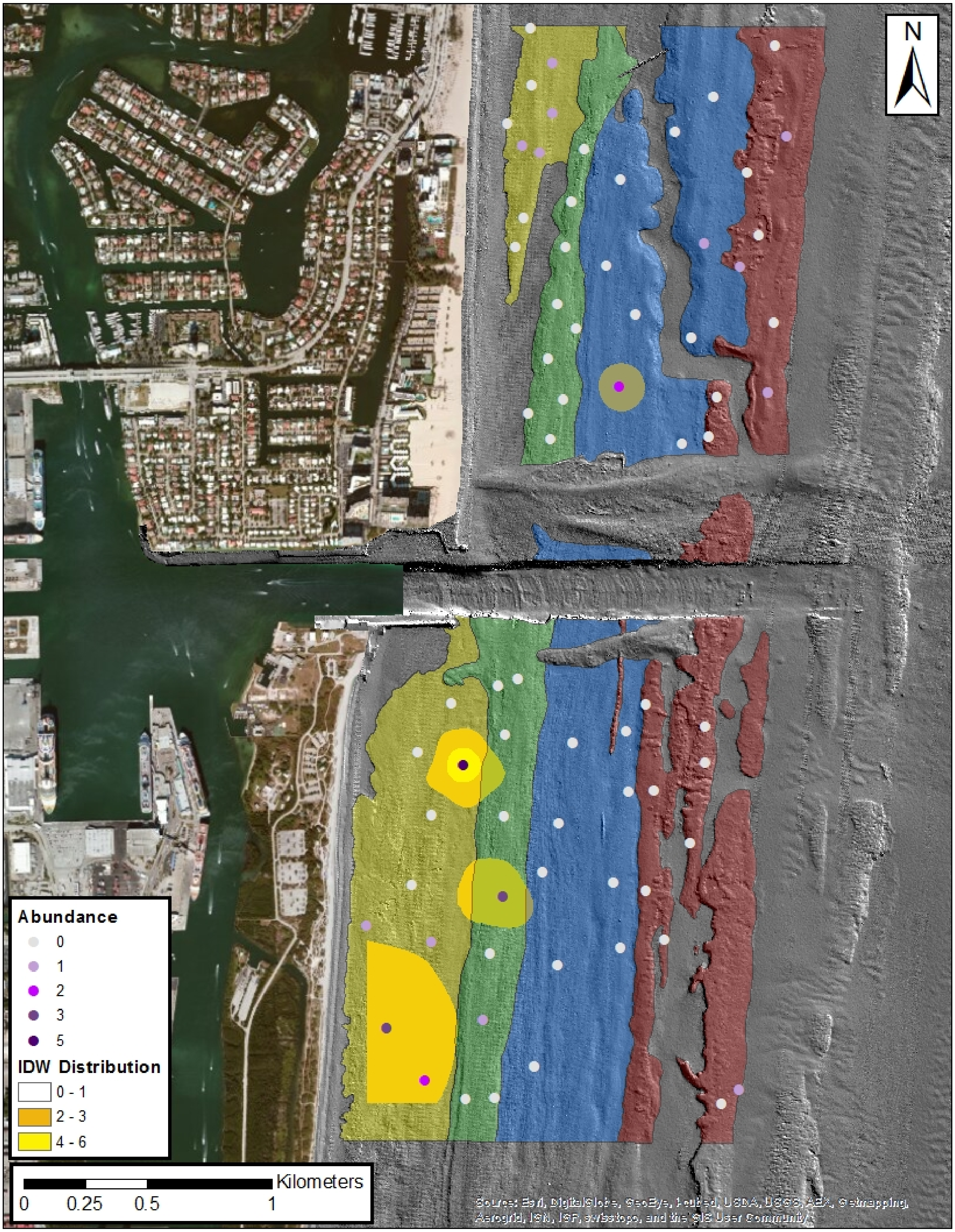

Figure 35. Interpolated distance weighted (IDW) distribution between sites and actual abundance values at each site of juvenile conch.

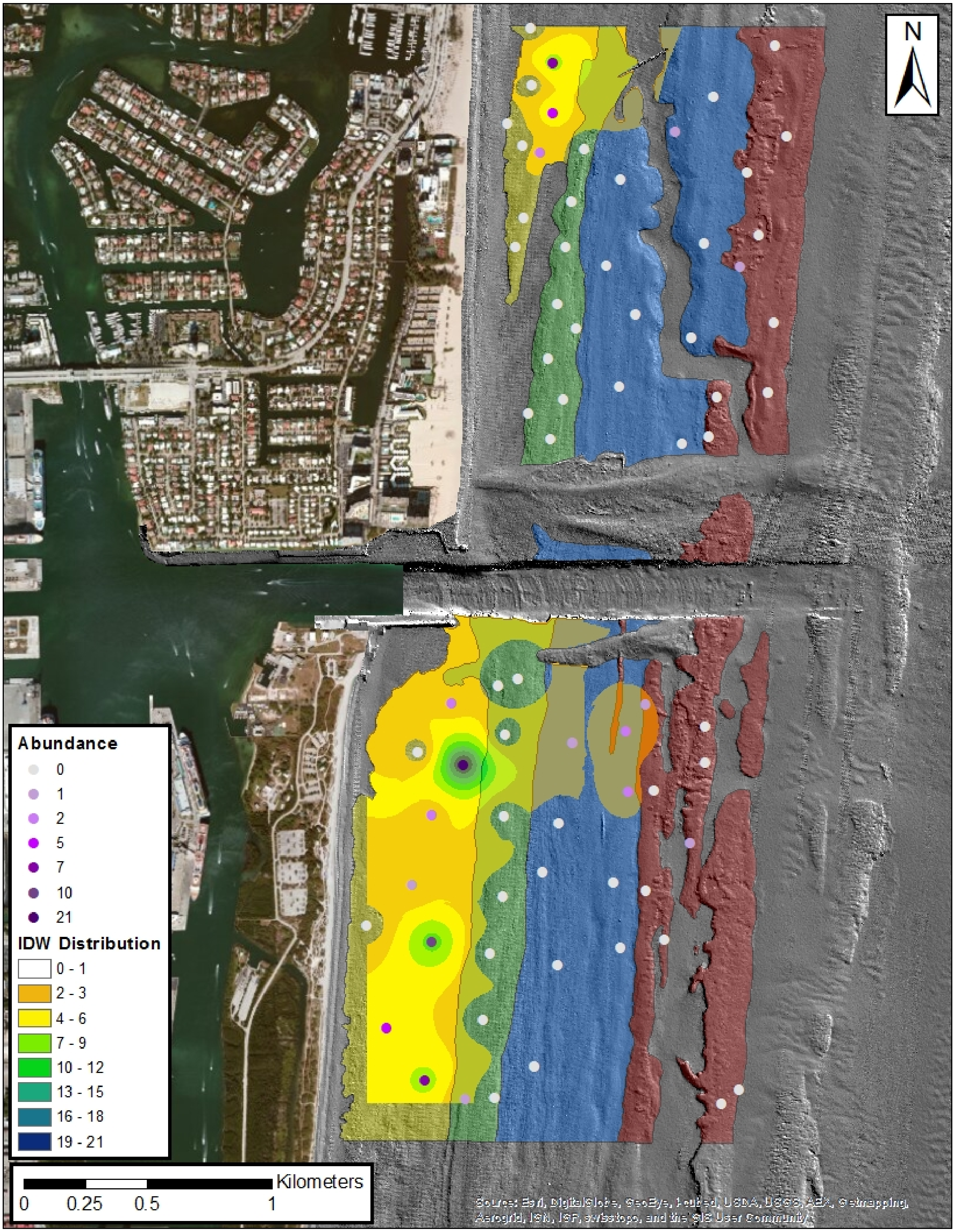


Figure 36. Interpolated distance weighted (IDW) distribution between sites and actual abundance values at each site of sub-adult conch.

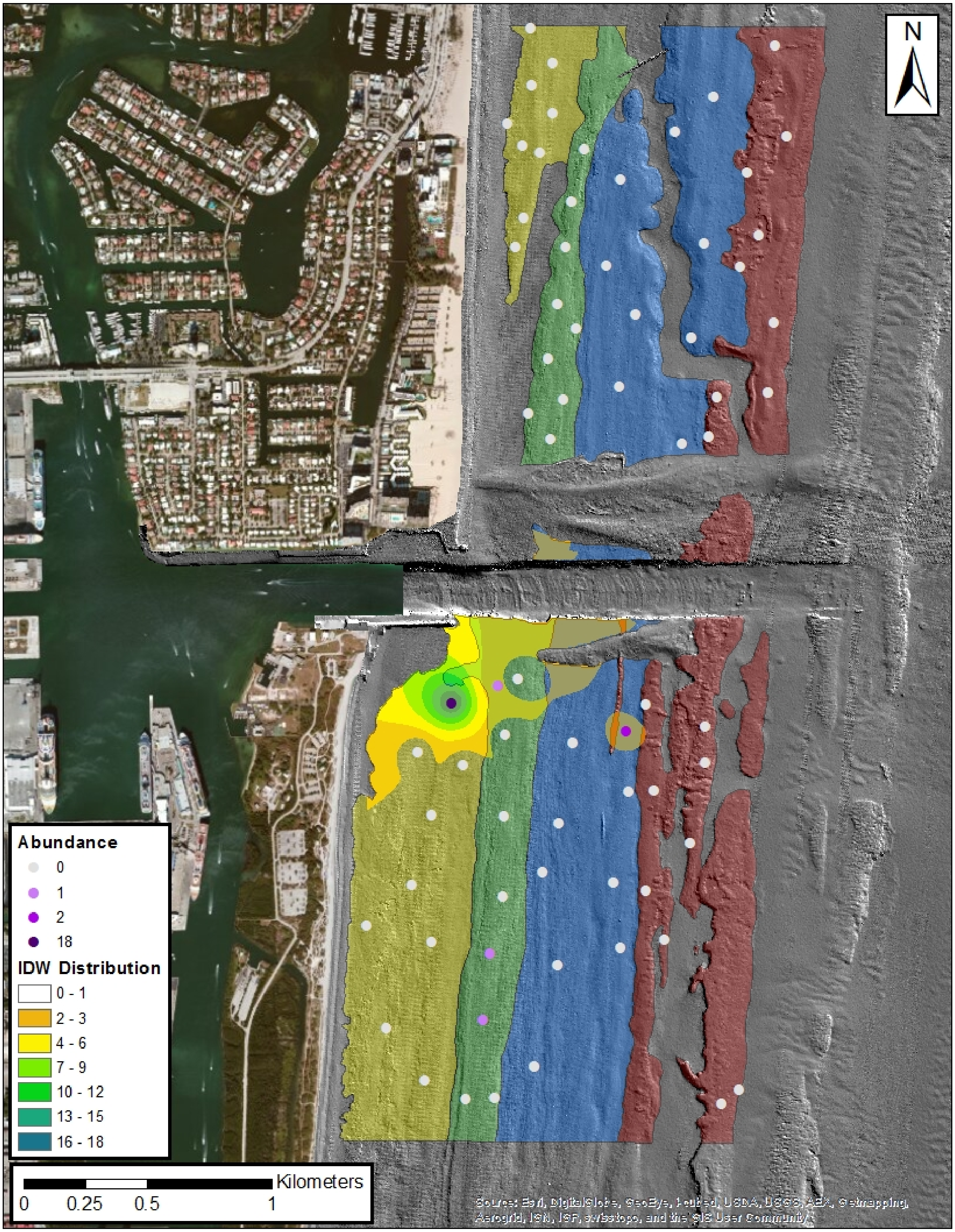

Figure 37. Interpolated distance weighted (IDW) distribution between sites and actual abundance values at each site of adult conch.

Getis Ord GI* hot spot and Anselin Local Moran I analyses identified two significant high clusters (HH ●) and hot spots (z-score +2, ●) for all conch at SCPW 5 and 7 (Figure 38). Hot spots for juvenile conch occurred at SCPW 4 and 7, and SR 5 (Figure 39). SCPW 4 had high clustering and SCPW 7 and SR 5 had significant high clustering surrounded by low clustering (LL or LH ●). One high clustering hot spot occurred at SCPW 7 for sub-adult conch (Figure 40). Adult conch had one significant high clustering hot spot located at SCPW 5 (Figure 41).

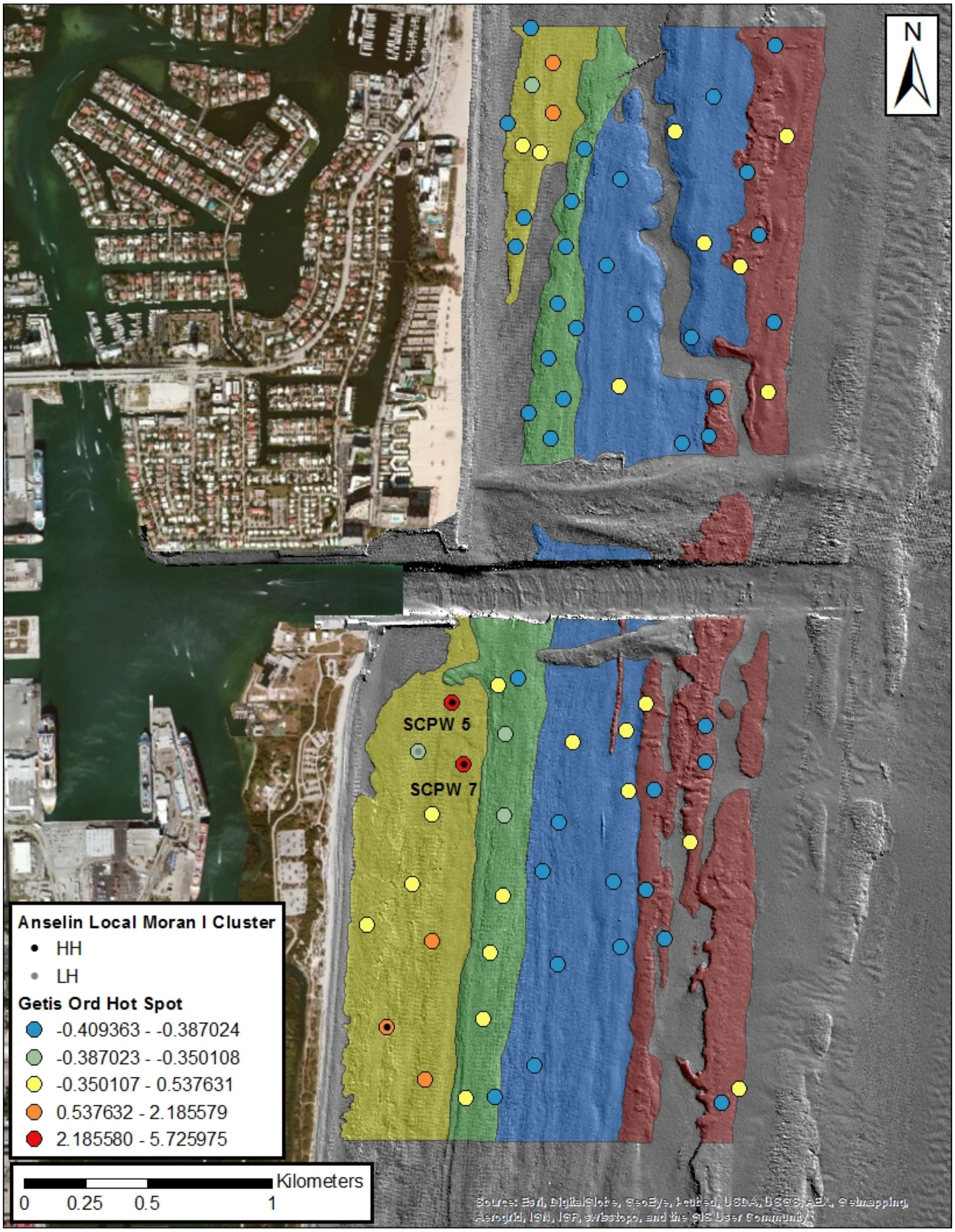

Figure 38. Getis Ord GI* hot spot (z-score value +2) analysis and Anselin Local Moran I cluster analysis showing high clustering (HH) and low clustering (LH) of all conch.

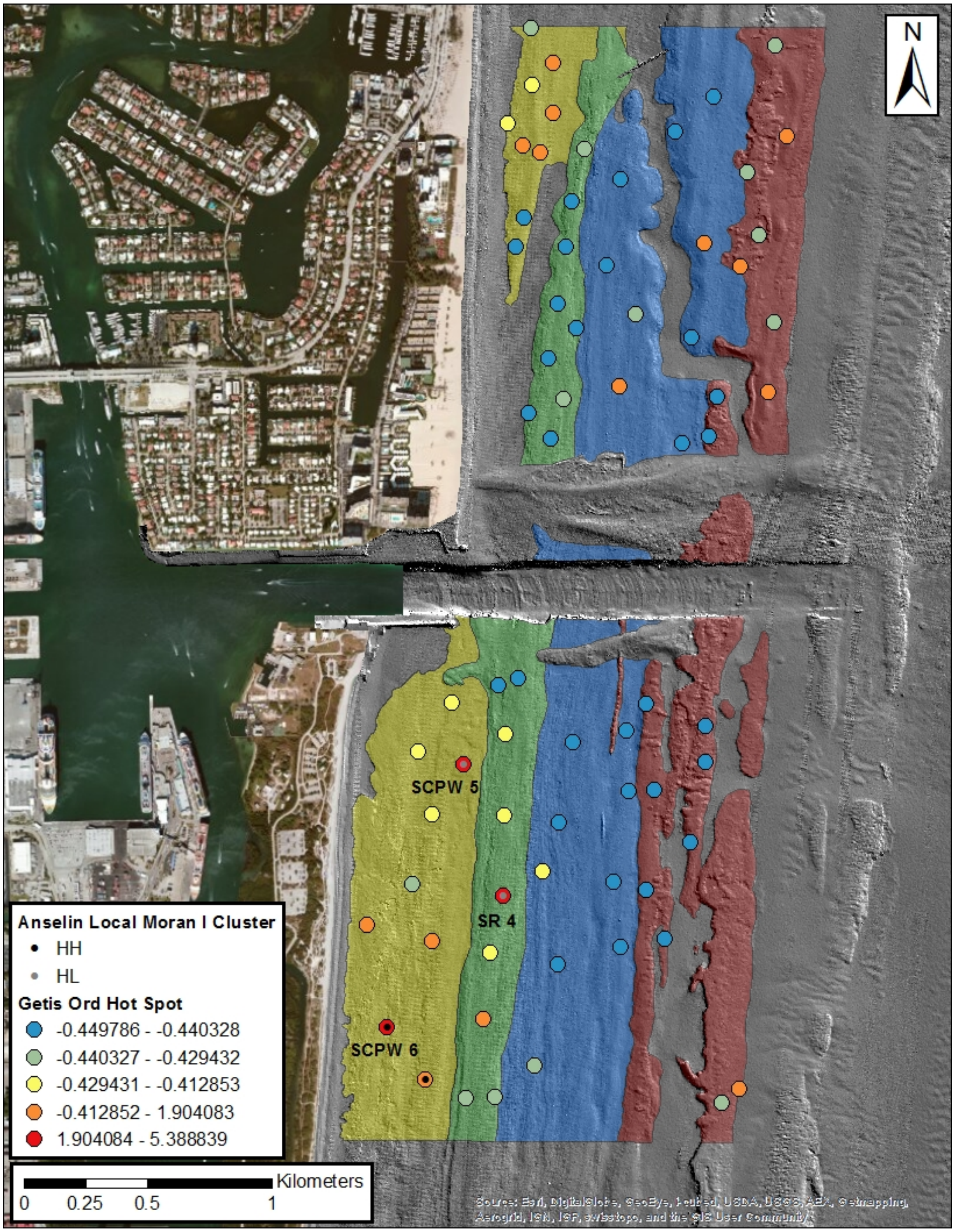


Figure 39. Getis Ord GI* hot spot (z-score value +2) analysis and Anselin Local Moran I cluster analysis showing high clustering (HH or HL) of juvenile conch.

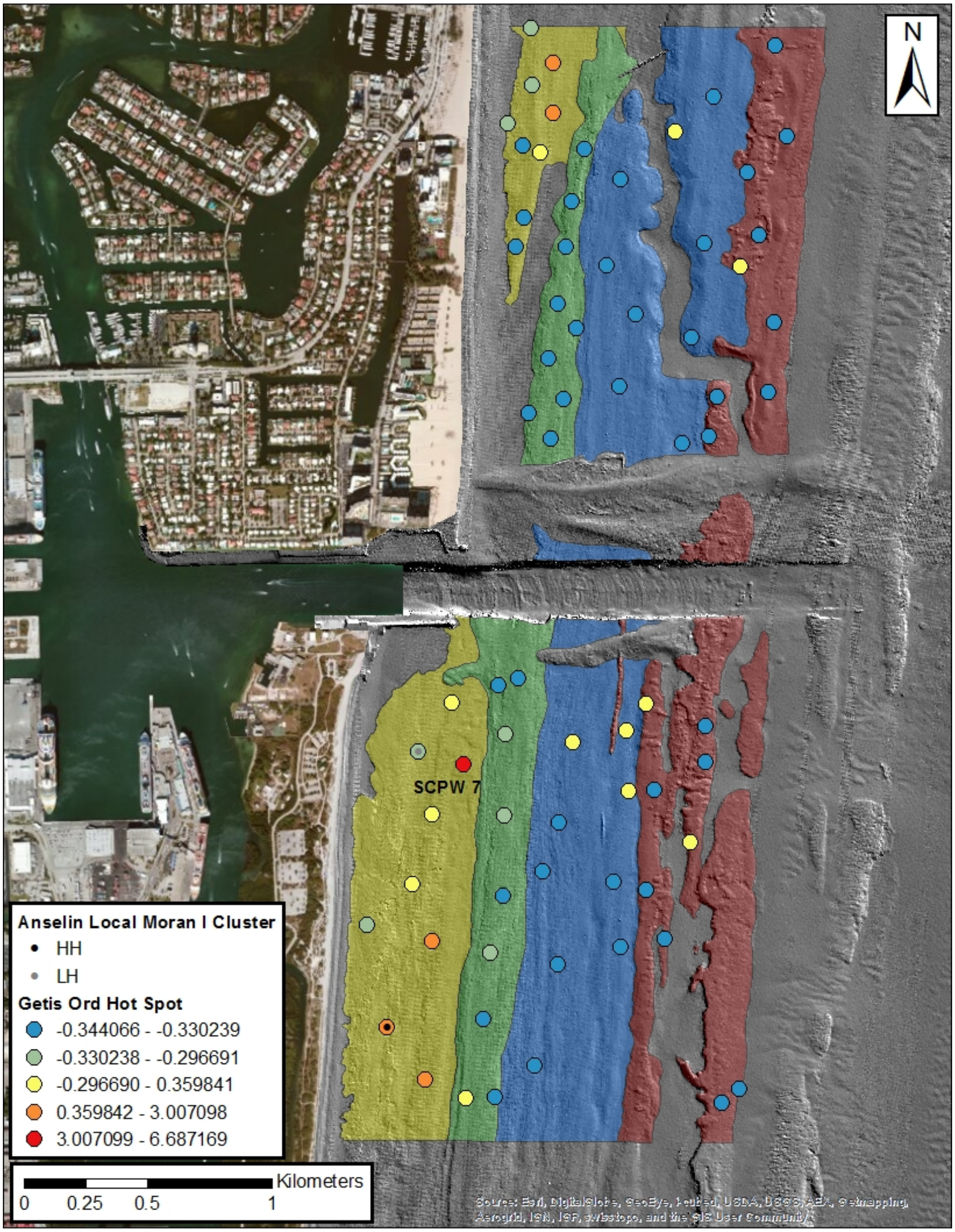


Figure 40. Getis Ord GI* hot spot (z-score value +2) analysis and Anselin Local Moran I cluster analysis showing high clustering (HH) and low clustering (LH) of sub-adult conch.

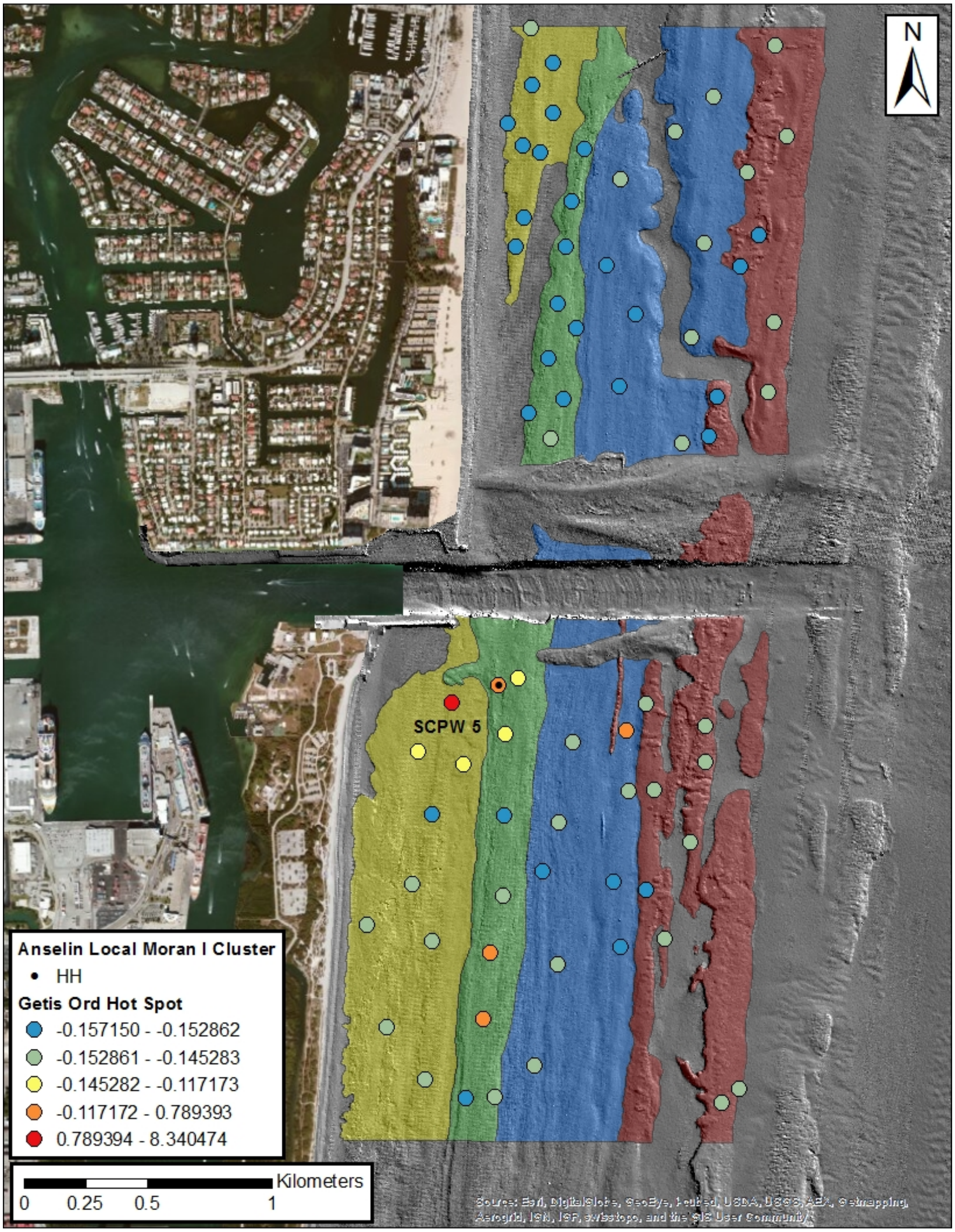

Figure 41. Getis Ord GI* hot spot (z-score value +2) analysis and Anselin Local Moran I cluster analyses showing high clustering (HH) of adult conch.

## 3.3 Aggregation Population Study

The skewed sex ratio from the broad-scale population study likely indicated an under-surveyed population. Since the majority of conch, found during the broad-scale study, were on the SCPW habitat and mostly at one particular site (SCPW 5), this habitat was targeted with a second effort to get a better understanding of this part of the population. During this survey, 525 *Strombus gigas*, 2 *Strombus costatus*, and 3 *Strombus raninus* were recorded.

### *Density*

Conch were found on every transect with no pattern of spatial distribution (Figure 42). Density of *S. gigas* was calculated for each transect by dividing the number of conch by the total transect area (length * 4 m). The *S. gigas* density, i.e., aggregation density, of the total survey area (10,600 $m^2$) was 495 conch/ha (0.05 conch/$m^2$). Density of *S. gigas* for each transect varied. Transect 3 had the highest density and Transect 1 had the lowest (Table 11). Since the southernmost transect near the edge of our study area had one of the highest densities (0.05 conch/$m^2$), one might assume that the distribution is likely to continue to the south but the full extent of the dense conch area is unknown.

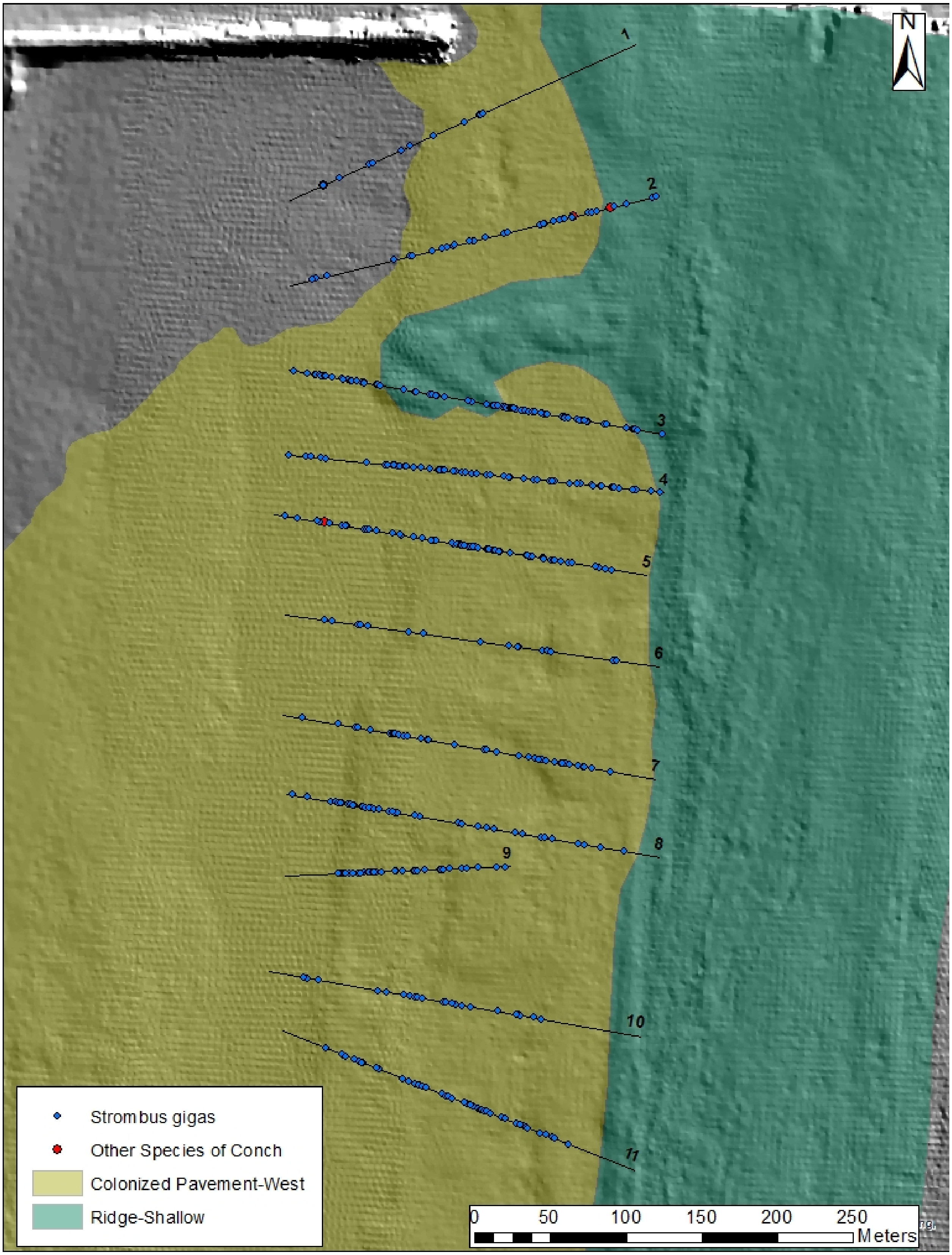

Figure 42. *Strombus gigas*, and other conch species locations along each transect.

Table 11. Density of *Strombus gigas* for each transect.

| Transect | Density (conch/ha) | Abundance |
|---|---|---|
| 1 | 0.014 | 14 |
| 2 | 0.040 | 40 |
| 3 | 0.103 | 103 |
| 4 | 0.068 | 68 |
| 5 | 0.80 | 80 |
| 6 | 0.018 | 18 |
| 7 | 0.004 | 44 |
| 8 | 0.042 | 42 |
| 9 | 0.068 | 41 |
| 10 | 0.025 | 25 |
| 11 | 0.050 | 50 |

### *Shell Length and Lip Thickness*

Shell length ranged from 2.7-27.8 cm with a mean of 22.6 cm (±0.1 SE) (n=525). This was similar to the mean shell length from the overall broad-scale population survey. Lip thickness ranged from 2.0-37.0 mm with a mean of 16.6 mm (±0.4 SE) (n=459). This was larger than the broad-scale population study. The same conch age classifications from the broad-scale population study methods were used for the age structure of conch for the aggregation population study which amounted to 66 juveniles, 219 sub-adults, and 240 adults (Figure 43). There was a much smaller percentage of juveniles in the SCPW population (12.6%) compared to the number of sub-adults (41.7%) and adults (45.7%). The mean shell length for each age class was 20.4 cm (±0.5 SE) for juvenile (n= 66), 23.0 cm (±0.1 SE) for sub-adult (n=219), and 22.9 cm (±0.1 SE) for adult (n=240) (Figure 44). One-way nonparametric ANOVA test showed significant differences in shell length between sub-adult and juvenile ($p=<0.0001$) and juvenile and adult ($p=<0.0001$).

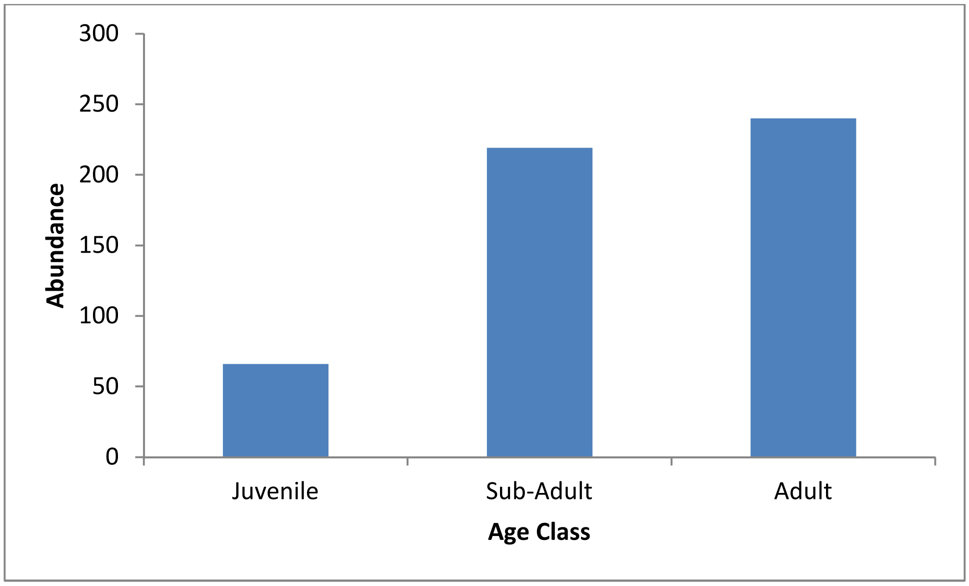

Figure 43. Abundance of *Strombus gigas* in each age class.

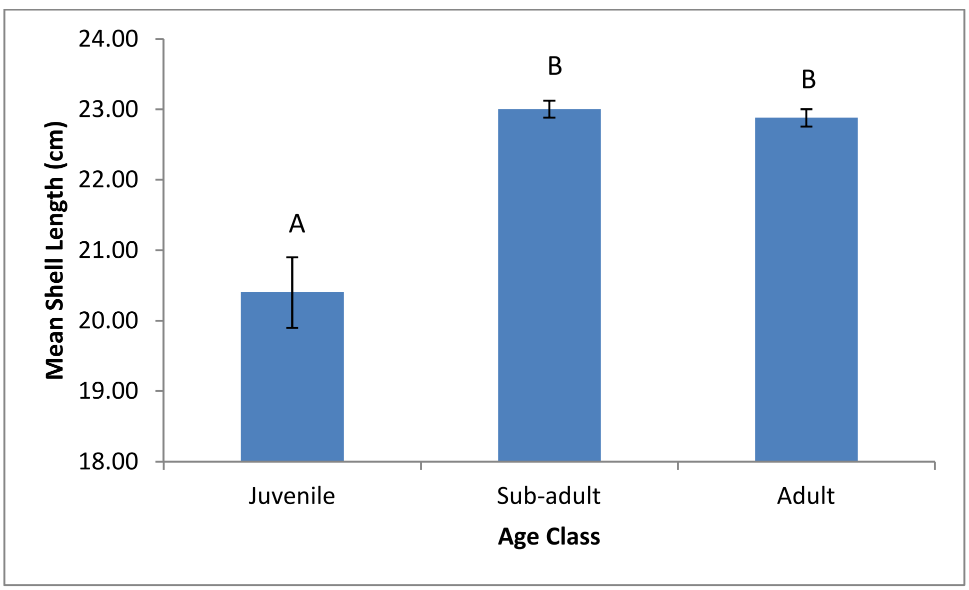

Figure 44. Mean shell length measurements of juvenile, sub-adult, and adult *S. gigas* with standard error bars. One-way nonparametric ANOVA tests showed significant differences in shell length between sub-adult and juvenile *S. gigas* (p=<0.0001) and juvenile and adult *S. gigas* (p=<0.0001).

### ***Mating and Sex***

A total of 246 conch (46.9%) were successfully sexed; 133 male and 113 female. There were 12 male and 7 female juveniles, 42 male and 59 female sub-adults, and 79 male and 47 female adults (Figure 45). This resulted in a sex ratio of approximately 1.18 males to every female. Mean shell length of sub-adult and adults combined for females and males was similar; females had a mean shell length of 23.3 cm (±0.2 SE) and males had a mean shell length of 22.8 cm (±0.1 SE). One-way nonparametric ANOVA test showed significant difference in shell length between sexes (p=0.0002). Males had a slightly larger lip thickness than females; males had a mean lip thickness of 18.8 mm (±0.6 SE) and females had a mean lip thickness of 15.3 mm (±0.8 SE). One-way nonparametric ANOVA test showed significant difference in lip thickness between sexes (p=0.0003).

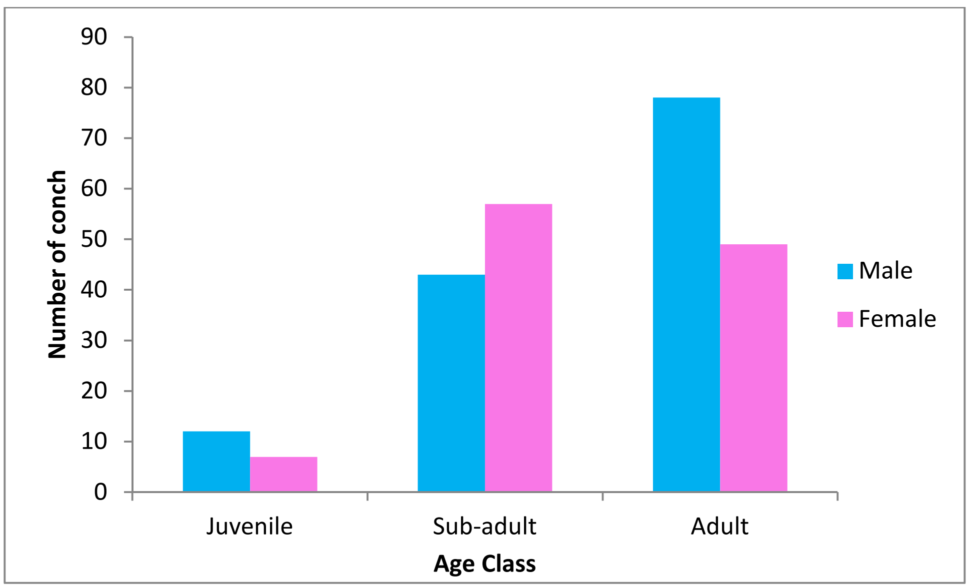


Figure 45. Abundance of male and female *Strombus gigas* in each age class.

There were 5 confirmed conch mating sightings, 1 sub-adult female and adult male pair, 1 sub-adult male and adult female pair, and 3 adult pairs (Figure 46). Egg masses and females laying eggs were identified throughout the study (Figure 47); these consisted of females laying eggs and females with almost complete egg masses. Thirty-three females were seen with eggs (20 adult and 13 sub-adult), equating to 31.1%

(33/106) of the sub-adult and adult female population. Twenty eight solitary egg masses were found throughout the study. Egg masses and females laying eggs were typically covered in sand. There were some occurrences where egg masses were not covered in sand and had a white stringy appearance. Eleven males were seen with egg strands wrapped around the verge and attached to the shell. Eggs that were not covered in sand tended to move along the bottom with current and became tangled in debris. The number of egg masses sighted supports that mating in this nearshore habitat is successful. Recruitment, however, is unknown.

Figure 46. Images of mating seen during the aggregation population study.

Figure 47. Various forms of eggs seen throughout the aggregation population study. Female *S. gigas* (top left) laying eggs, male *S. gigas* (top right) tangled in egg strands, solitary egg mass covered in sand (bottom left), and solitary egg mass not covered in sand (bottom right).

## 4.0 Discussion

*Strombus gigas* exists along portions of the northern Florida reef tract and nearshore habitats in low abundance. Conch have previously been found throughout the region in low densities and have been sighted as far north as Martin County and Port Canaveral, FL (FWC, unpublished data). The broad population study found low densities in four habitats both north and south of Port Everglades inlet and high densities just south of Port Everglades, FL along John U. Lloyd State Park. During this study, conch densities were higher south of the inlet and the habitat with the majority of the conch was colonized pavement west (CPW). Colonized pavement east (CPE), shallow ridge (R), and inner reef (IR) contained very low numbers. Specifically, the south colonized pavement west (SCPW) habitat contained the highest mean density (0.0361 conch/ $m^2$).

Coincident with a high conch density, SCPW benthic cover composition was different from all other habitats. The SIMPER test showed SCPW sites contained the highest macroalgae and sand cover of all the habitats. Habitats east of SCPW exhibited a cross-shelf trend containing less macroalgae and sand and more coral, gorgonians, and turf algae. Although densities were lower, a similar cross-shelf trend was evident north of the inlet where the majority of the conch were found on north colonized pavement west (NCPW). The NCPW had the highest macroalgae and sand cover of the northern sites and other habitats had higher coral, gorgonians, and turf algae cover. This distinction was supported by the MDS analysis which showed greater separation of NCPW sites from most of the other habitats, although the ANOSIM showed that separation was not as strong as SCPW. Conch associated most with the colonized pavement west sites and those had the highest composition of macroalgae and sand cover.

Without formal comparisons it is difficult to know if the habitats conch utilize in southeast Florida are different from areas in the Florida Keys and throughout the Caribbean. In other areas, conch utilize seagrass beds for food, mating, and nurseries. Juvenile and adult conch often utilize different habitats. For example, juvenile conch in St. John, U.S. Virgin Islands, are found on patchy seagrass beds, continuous seagrass beds, and patchy macroalgae plains. As the juveniles grow closer to adult size they begin to move into deeper water with mixed sand and macroalgae (Doerr and Hill, 2008). In the Florida Keys, conch are found in seagrass, sand, hard bottom, and rubble habitats. Seagrass habitat characteristics vary between Florida and other areas in the Caribbean. In the Exuma Cays, Bahamas, seagrass beds have relatively low biomass, low shoot densities, short blades, and a relatively silt free substrate (Stoner *et al*., 1996). In the Florida Keys, seagrass beds are comprised of long thickly distributed *Thalassia testudinum* with silty substrate (Stoner *et al*., 1996).

Most of the seagrass habitat in the Florida Keys is on substrate characterized by fine sediment which is poor habitat for conch (Glazer and Kidney, 2004), thus it's not surprising that the highest concentration of conch in the Florida Keys occurred on hardbottom habitat (1.54- 2.40 conch/ha) while only 0.18 conch/ha occurred on *Thalassia testudinum* beds (Stoner *et* al., 1996). During non-reproductive seasons conch use rubble with coarse sand habitat, whereas during reproductive seasons they use homogenous coarse sand plains. Grain size is important for reproduction of conch. When a female lays an egg mass, the egg strand comes out of the egg grove down the front of the foot, and is deposited in the sand. The egg strand is sticky to immediately collect sand to increase the density of the eggs so they stay on the bottom and do not float away. Sand also provides camouflage from predators (Davis, 2005). Silt is not an appropriate grain size because it would be too small. The rubble with coarse sand habitat used during non-reproductive seasons may be too large of a grain size compared to that of the homogenous coarse sand plains used during reproductive seasons. During this study, bare solitary egg masses were found. Perhaps the grain size of the sediment at the egg-laying location was not appropriate to stick to the eggs.

Habitat preference may be influenced by predators, forage, hydrology, sediment organics, and larval supply (Glazer and Kidney, 2004). Stoner *et al*. (1996) suggest the availability of epiphytes and appropriate macroalgae are probably more important for conch aggregations than seagrass blades that are inedible. Locally, there are no large *Thalassia testudinum* seagrass beds (Walker, 2012) but the nearshore sand, rubble, pavement environment is apparently sufficient to sustain local populations. The unique algal community of SCPW may provide the appropriate food availability for conch. The macroalgae species unique to SCPW was *Lobophora variegata*. This species has wide flat blades similar to seagrass which may provide abundant surface for epiphytes. The relatively higher percentage of sand on the nearshore may also provide them with adequate reproductive and egg-laying habitat.

The effect of fishing pressure may also affect actual or apparent habitat preference. Conch may be removed in some certain areas and not others. Conch may become vulnerable to harvest in areas of shallow waters during open fishing driving them to colonize deeper seagrass or sand plains (Glazer and Kidney, 2004). Queen conch harvesting is almost nonexistent in Broward Country, FL except for a small amount of poaching so affects of fishing on the observed distributions are unlikely.

The overall density for the entire broad-scale population study (70.6 conch/ha) was high compared to other areas throughout the tropical western Atlantic (Table 12). This is a high density of conch for a relatively high latitude location. The broad-scale population density falls within the cross-shelf thresholds defined by Stoner and Ray-Culp (2000) for a reproducing population. The density of the aggregation on SCPW (0.05 conch/$m^2$) was similar to aggregations in the Florida Keys and thus justifies it being labeled an aggregation (Figure 48). Densities of 11 aggregations were reported from surveying in 2007 (Glazer and Delgado, 2007). The density of conch at Port Everglades was similar to those at Grecian Rocks (0.049 conch/$m^2$), Alligator (0.044 conch/$m^2$), and Delta Shoal (0.050 conch/$m^2$) in the Keys. Looe Key had the highest density (0.218 conch/$m^2$). The overall density of conch in all aggregations surveyed throughout the Florida Keys in 2007 was 0.074 conch/$m^2$ with a total area of 345,008 $m^2$ (Glazer and Delgado, 2007). The density on SCPW (495 conch/ha) is above the Florida minimum threshold where reproduction does occur but has not reached the 800 conch/ha level where reproductive output levels out (Glazer and Delgado, 2012). The population density near Port Everglades inlet is high enough to maintain population growth and reproductive output.

Table 12. Average densities of *Strombus gigas* estimated in various locations in the tropical Western Atlantic.

| Location | Density (conch/ha) |
|---|---|
| Port Everglades, FL (present study) | 70.60 |
| Florida Keys 1990 (Glazer and Berg, 1994) | 1.54 |
| Bermuda Platform (Berg *et al*., 1992b) | 0.52 |
| Little Bahama Bank (Smith and van Nierop, 1984) | 28.50 |
| Great Bahama Bank (Smith and van Nierop, 1984) | 20.79 |
| West Coast of Puerto Rico (Marshak *et al*., 2006) | 6.208- 6.431 |
| St. Thomas and St. John U.S. Virgin Islands (Schweizer and Posada, 2002) | 12.25 |
| Venezuela (Schweizer and Posada, 2002) | 18.78 |

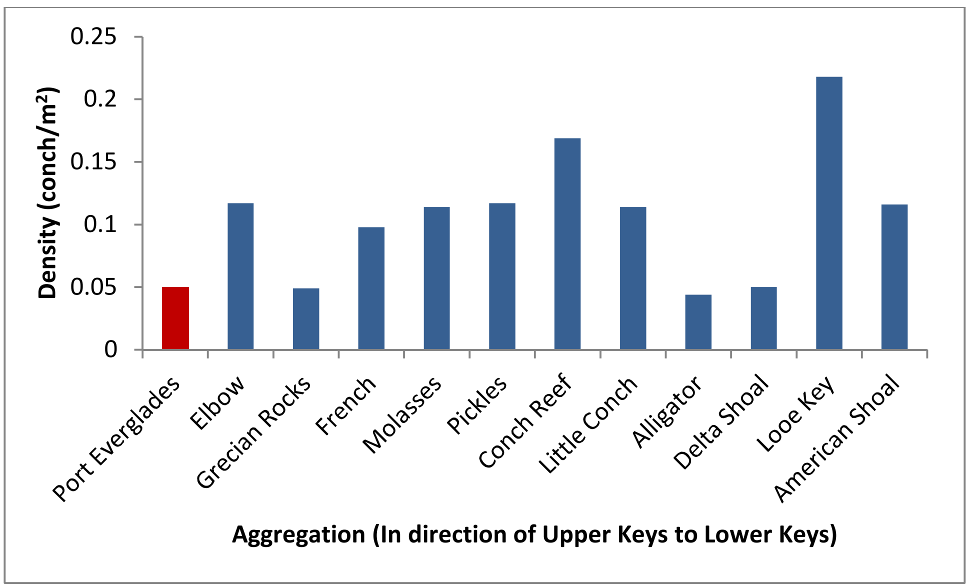


Figure 48. Densities reported from 11 aggregations in the Florida Keys conducted in 2007 and Port Everglades in 2013.

In the Florida Keys mating only occurs in offshore aggregations. No mating or egg mass production has been seen in nearshore aggregations where adults are present (Glazer and Berg, 1994). Conch in offshore areas developed normal gonads while conch in nearshore areas had no reproductive tissue and were unable to reproduce (McCarthy *et al*., 2000). Translocation of conch between the nearshore and offshore habitats showed reproductive failure is due to an environmental condition and removing nearshore conch to suitable offshore habitat can restore reproductive viability (Delgado *et al*., 2004). Zinc and copper were found at increased levels in nearshore conch tissues and has been known to impact reproduction in marine snails (Spade *et al*., 2010). Nearshore reproductive failure is possibly a result of exposure to heavy metals that are likely to accumulate close to shore (Spade *et al*., 2010). No definitive cause of reproductive failure has been identified and research is on-going to determine the cause and mechanism. The Port Everglades SCPW aggregation was first studied by Bryan and Walker (2005) where they identified its location, estimated densities, and confirmed mating. The evidence of egg masses, females laying eggs, and 6 mating sightings in my study confirms that mating is still active and successful in the southeast Florida nearshore population. The 11 males that were seen with egg strands wrapped around the verge and attached to the shell may have become tangled in the eggs during copulation since they can mate simultaneously as a female lays eggs (Randall, 1964). I found 29.2% of the conch sexed as females were laying eggs, thus a high level of conch reproduction does occur on the northern Florida Reef Tract nearshore habitats. This is the first published record of a mating aggregation on nearshore habitat on the Florida Reef Tract. However, there was a much smaller abundance of juveniles compared to the number of adults present, suggesting either recruitment may be low or this area is used by older conch as a mating area and a nursery area may exist elsewhere.

Male to female sex ratios were different between the broad-scale (1:2.24) and the aggregation studies (1.18:1). The typically observed *S. gigas* sex ratio is 1:1 (Randall, 1964). Issues faced when determining sex of individual conch included not being able to sex small juveniles, conch being shy and uncooperative, and the time it would take for a conch to right themselves exceeding the divers' bottom time. These issues may have affected the sex ratio because sexing depended on the conch's cooperation. Therefore mostly older and non-skittish conch were sexed. In part, the sex ratio was used as a gauge to determine how well the population was sampled. It is likely that the extreme difference between the broad-scale ratio and the expected was due to low sample size. Only 122 conch were found in the broad-scale study of which 55 cooperated in sexing. It is doubtful that this small portion of the population sexed gave a good estimation of the overall population's sex ratio. The aggregation study counted 525 conch of which 246 cooperated. The higher numbers likely helped in getting closer to an expected sex ratio resulting in a more accurate measure. The only way to get an accurate sex ratio is to sacrifice a large number of individuals and determine the sex of each, eliminating the cooperation issue. However this is not easy to do on a protected species and may not be worth the sacrifice. My results showed that given enough cooperation, a sex ratio can be obtained that's reasonably close to expected without sacrificing individuals.

Lip thickness is used as a surrogate for determining age. Once conch reach its terminal shell length it begins to increase in lip thickness (Stoner *et al*., 2012b). This is the onset of sexual maturity but, a flared lip does not guarantee sexual maturity (Stoner *et al*., 2012b). Using lip thickness to determine age is relative, there is no standard age classification and it varies between regions. Throughout the tropical western Atlantic and Caribbean, size at sexual maturity is variable and site specific. Differences between sites could be associated with nutrients, temperature, and overall growth rates (Stoner *et al*., 2012b). For example, shell length at sexual maturity in southern Mexico and the

Bahamas was about 170 mm (Stoner *et al*., 2012b). In the Colombian Islands shell length at sexual maturity was 249 mm for females, 234 mm for males, and 241 mm for both sexes. In this study, shell length measurements were similar between all conch and were not informative. There was no significant difference in shell length between adult and sub-adult conch. This was expected because once conch reach their terminal shell length they begin to increase in lip thickness. Recent studies show sexual maturity with lip thickness measurements for females ranging from 17.5-26.2 mm and males ranging from 13.0-24.0 mm (Stoner *et al*., 2012b). The earliest sexual maturity is seen in Belize at lip thickness measurements of 4 mm for females and 3 mm for males (Stoner *et al*., 2012b). A minimum lip thickness of 5 mm for sexual maturity is seen in Puerto Rico, 5-10 months after the initial shell lip formation (Appledoorn 1988a). In Colombia, lip thickness at sexual maturity was 17.5 mm for females, 13.0 mm for males, and 13.5 mm for both sexes (Avila-Poveda and Baqueiro-Cárdenas, 2006). In the Barbados, lip thickness at sexual maturity was between 13.0-19.0 mm (Bissada, 2011). In the Bahamas, the minimum lip thickness measurement for sexual maturity can be greater than 20.0 mm (Stoner *et al*., 2012b).

In this study, sub-adult (1-15 mm lip thickness) and adult (>15 mm lip thickness) conch were seen mating and with eggs suggesting that *a priori* assumptions about size (e.g., lip thickness) at maturity were not appropriate for this population. Of the total conch sexed as females (n=113), 29.2% (33/113) were seen with eggs. For females with eggs, 39.4% (13/33) were sub-adults and 60.6% (20/33) were adults. For those females without eggs, 8.8% (7/80) were juveniles, 57.5% (46/80) were sub-adults, and 33.8% (27/80) were adults. Sexual maturity likely occurs in the sub-adult age class. The minimum lip thickness of gravid females was 7 mm, but this was a rare occurrence (Figure 49). Although in low frequency, seven (21.2%) gravid females with a lip thickness between 7 and 12 were seen. The findings from this study fit within those of other studies. Some conch are sexually mature with a lip thickness of less than 7 mm, although in most locations they become mature at a larger thickness (Stoner *et al.* 2012b). Stoner *et al*. (2012b), found that females with a lip thickness less than 5 mm had no germ tissue present, females with lip thickness less than 10 mm were immature and females with lip thickness greater than or equal to 15 mm were capable or reproduction. They also found that soft tissue weights and gonad weights decreased slightly for conch with a lip thickness of 22 to 25 mm suggesting older conch may have a reduced number of eggs (Stoner *et al*., 2012b). Because size and lip thickness at sexual maturity is variable and site specific, it is important to develop an appropriate age classification for this area to better estimate population demographics without having to sacrifice large numbers of the population. A better age cut-off for sexually mature adult conch on the northern Florida Reef Tract might be >12 mm instead of >15 mm. The distribution of female lip thicknesses showed that 78.8% of gravid females had a lip thickness >12 mm while 50% of non-gravid females were ≤12 mm (Figure 49). Additional studies with this population would be necessary to confirm size at sexual maturity.

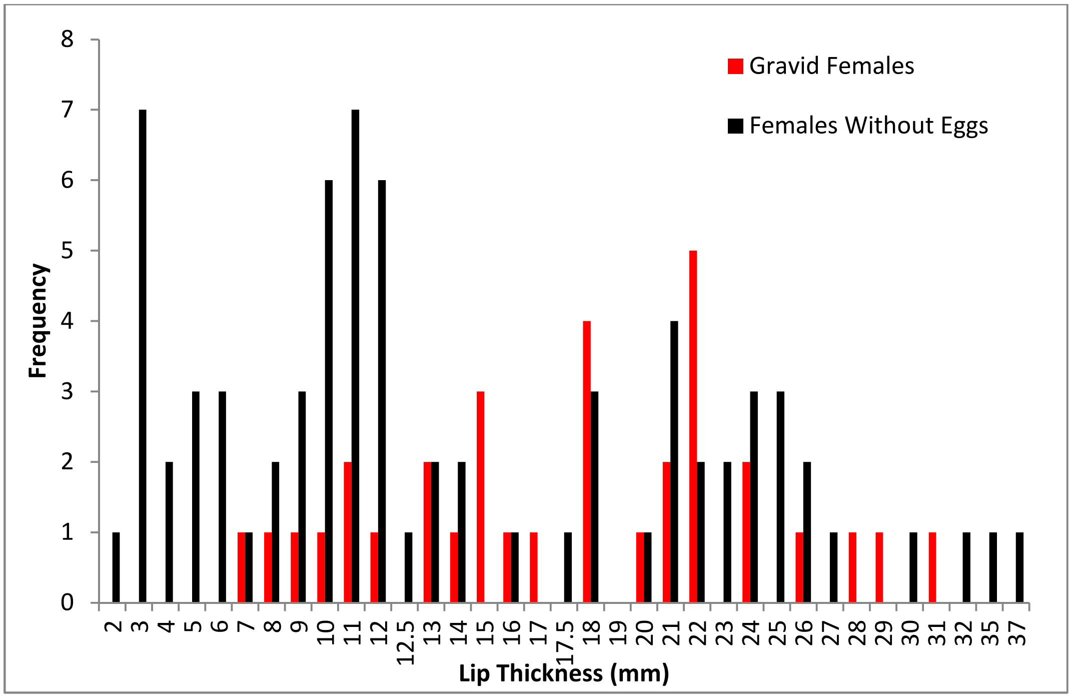

Figure 49. Lip thickness frequencies of gravid females and females without eggs.

Most countries throughout the Caribbean use shell length for harvesting regulations, limits, and quotas. This does not manage the population appropriately as shell length is not always a good surrogate for maturity. Recently, more countries have begun to use lip thickness with shell length to regulate size limits (Stoner *et al*., 2012b). Understanding the size at sexual maturity, age, and population growth is important for queen conch fishery management. Size at sexual maturity varies between sites thus, age classification and regulations need to be site specific.

It is unknown if Port Everglades inlet is affecting migration. Conch were found on both sides of the channel and similar patterns were found across habitats. Although benthic cover varied between NCPW and SCPW, they were more similar to each other than to the other habitats with fewer conch, indicating it may not be the inlet but rather a habitat preference or availability. The Port Everglades inlet channel may affect along-shore migration, but perhaps not as dramatically as Hawk Channel in the Florida Keys. Hawk Channel is a geographical barrier made up of fine, soft sediment that prevents conch migrating offshore into spawning aggregations (Glazer and Berg, 1994). There are three subpopulations of conch in the Florida Keys. The nearshore population is found adjacent to the island chain in shallow water hardbottom habitat. This population is affected by Hawk Channel and exhibits reproductive failure. The back reef population is found in shallow water on the reef flat with habitat primarily composed of rubble, sand, and seagrass. Reproduction occurs in this population. The deepwater population is found on the seaward side of the reef on sand plains in water approximately 10-25 m deep. Reproduction also occurs in this population (Glazer and Kidney, 2004). Port Everglades channel is comprised of coarse sediment as southerly long-shore drift causes beach sand to spill over the jetty and into the channel. Conch have been seen in the sand at the bottom of the channel during other work (Walker pers. comm.).

Climate change is expected to have effects on corals and coral reefs. Severe annual bleaching is predicted to occur by 2055 and acidification by 2034. Severe annual coral bleaching is expected to start 10 to 15 years later at high latitude reefs than for reefs in low latitudes. Reefs in high latitudes may experience ocean acidification before bleaching. The high latitude reefs have more time to be exposed to the effects of ocean acidification because the onset of severe bleaching occurs later (Van Hooidonk *et al*., 2013). The northern Florida Reef Tract is a high latitude reef projected to be impacted by ocean acidification. Corals and other invertebrates grow at pace with or just ahead of the rate at which biological and chemical erosion erodes reef framework (Van Hooidonk *et al*., 2013). Conch may be affected by ocean acidification and habitat loss by altering the ecosystem and habitat they utilize. Conch shells are made up of calcium carbonate and ocean acidification may affect the ability for conch to maintain their shells. Previous studies showed decreased calcification rates, reduced shell size, shell dissolution, tissue weight loss, and reduced feeding activity of the Pacific oyster (*Crassostrea gigas*) and blue mussel (*Mytilus edulis*) with increased acidity (Gazeau *et al*., 2007; Bamber, 1990). Strawberry conch (*Strombus luhuanus*) showed a decrease in shell growth with a 200 ppm increase in CO2 (Shirayaman and Thornton, 2005). Their biology is dependent on environmental cues for reproduction. Water temperature (Davis, 2005) and photoperiod play an important role in the timing of conch reproduction (Stoner and Sandt, 1992). Mating occurs when water temperatures are warmest (Davis, 2005). Stoner and Sandt (1992) found that mating increased as a linear function of bottom water temperature and declined during and after the warmest period.

Future research should include expanded broader-scale surveys to determine if other aggregations exist and monitoring to examine the effects of environmental change on this vulnerable species. Tagging studies could determine the degree to which the channel limits connectivity between these two aggregations. Additional benthic surveys and feeding studies are needed to assess the influence of benthic communities on conch distribution. Further research to determine age at sexual maturity and quantify recruitment is needed to determine reproductive output and productivity. Genetic or environmental studies may be useful in understanding why this population is able to reproduce while the nearshore populations in the Florida Keys are unsuccessful and to look at connectivity along the Florida Reef Tract. Looking at seasonality, migration, and monitoring the population density may provide new insight on this aggregation.

## 5.0 Management Recommendations

*Strombus gigas* is a CITES listed species that inhabits and reproduces in the nearshore environment of Broward County, FL. Recently, a petition was submitted to list *S. gigas* on the ESA list as threatened or endangered. This aggregation would likely not exist if it weren't for the conch fishing moratorium in Florida. This supports the idea of relieving fishing pressure to produce large aggregations of conch. It is important to understand where conch might reside to help inform conservation efforts in fished areas. Using lip thickness as a surrogate to determine age should be specific to its locations. Age classification may vary between different locations throughout Florida. The aggregation located near Port Everglades is a large aggregation within meters of shore and one of the largest seaports in Florida. This study shows that the nearshore environments can provide adequate habitat for large aggregation of mating conch and should perhaps be conserved elsewhere. Managers should consider conch when proposing beach nourishment and nearshore construction projects. Grain size should be considered for beach nourishment because it is necessary for conch reproduction. If the grain size is too small or too large the sand, which is used for camouflage from predators, may not stick to conch eggs. Nearshore construction projects and anthropogenic impacts may alter habitats conch utilize. Dredging should also be considered as it can alter habitat and depth creating geographical barriers and poor conch habitat. Climate change could move conch northward to areas where they may have never existed previously. This might be affected by nearshore hardbottom burial and freshwater releases into the estuaries for water management purposes. This research will help inform managers about the importance of nearshore habitat for conch and what needs to be considered when proposing nearshore construction projects.

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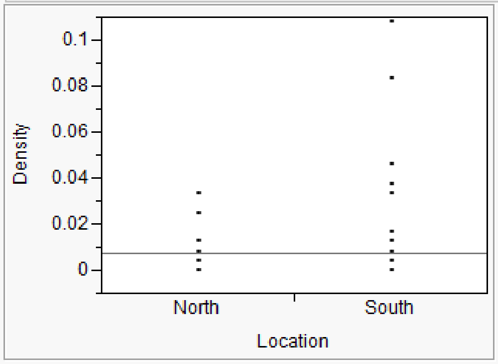
**Appendix 1. JMP ANOVA results for the broad-scale population study mean density by location, habitat type, and site habitat.**

### Oneway Analysis of Density By Location




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| North | 36 | 1138.00 | 1314.00 | 31.6111 | -2.239 |
| South | 36 | 1490.00 | 1314.00 | 41.3889 | 2.239 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 1490 | 2.23869 | 0.0252* |

#### 1-way Test, ChiSquare Approximation

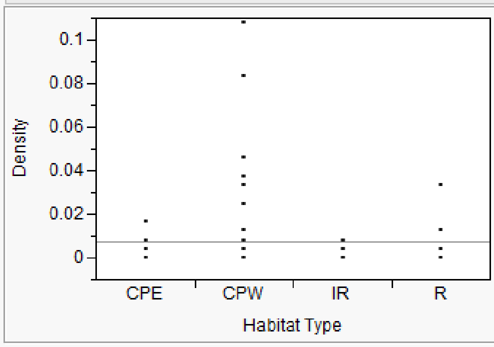
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 5.0403 | 1 | 0.0248* |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| South | North | 9.750000 | 4.355217 | 2.238694 | 0.0252* | 0 | 0 | 0.0041667 |

## Oneway Analysis of Density By Habitat Type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| CPE | 18 | 598.500 | 657.000 | 33.2500 | -0.854 |
| CPW | 18 | 886.500 | 657.000 | 49.2500 | 3.373 |
| IR | 18 | 576.000 | 657.000 | 32.0000 | -1.186 |
| R | 18 | 567.000 | 657.000 | 31.5000 | -1.318 |

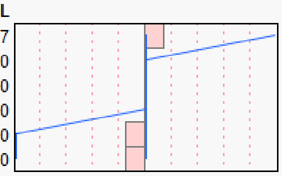
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 11.5129 | 3 | 0.0093* |

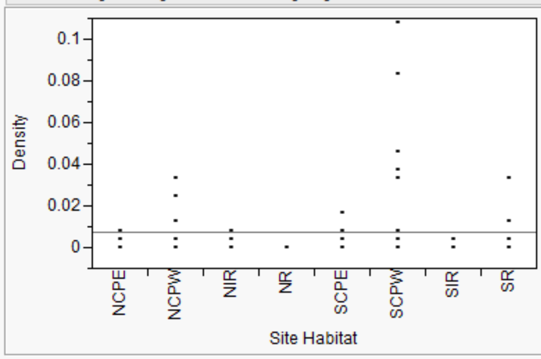
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| CPW | CPE | 8.11111 | 3.275934 | 2.47597 | 0.0133* | 0.004167 | 0.000000 | 0.0291667 |
| R | IR | -0.44444 | 2.841305 | -0.15642 | 0.8757 | 0.000000 | 0.000000 | 0.0000000 |
| IR | CPE | -0.66667 | 2.922817 | -0.22809 | 0.8196 | 0.000000 | 0.000000 | 0.0000000 |
| R | CPE | -0.88889 | 2.854681 | -0.31138 | 0.7555 | 0.000000 | 0.000000 | 0.0000000 |
| R | CPW | -8.50000 | 3.234241 | -2.62813 | 0.0086* | -0.004167 | -0.029167 | 0.0000000 |
| IR | CPW | -8.72222 | 3.264771 | -2.67162 | 0.0075* | -0.004167 | -0.029167 | 0.0000000 |



## Oneway Analysis of Density By Site Habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| NCPE | 9 | 292.500 | 328.500 | 32.5000 | -0.685 |
| NCPW | 9 | 355.000 | 328.500 | 39.4444 | 0.501 |
| NIR | 9 | 292.500 | 328.500 | 32.5000 | -0.685 |
| NR | 9 | 198.000 | 328.500 | 22.0000 | -2.507 |
| SCPE | 9 | 306.000 | 328.500 | 34.0000 | -0.424 |
| SCPW | 9 | 531.500 | 328.500 | 59.0556 | 3.905 |
| SIR | 9 | 283.500 | 328.500 | 31.5000 | -0.858 |
| SR | 9 | 369.000 | 328.500 | 41.0000 | 0.771 |

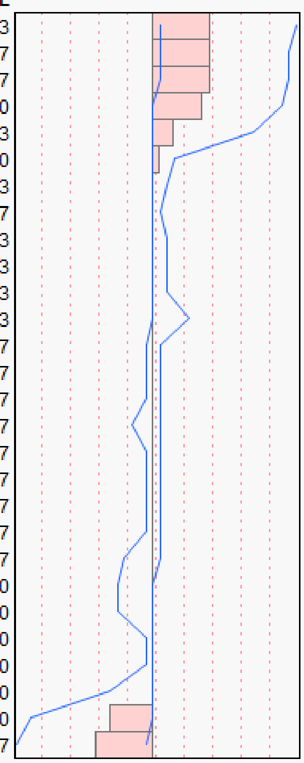
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 21.3828 | 7 | 0.0032* |

## Nonparametric Comparisons For Each Pair Using Wilcoxon Method

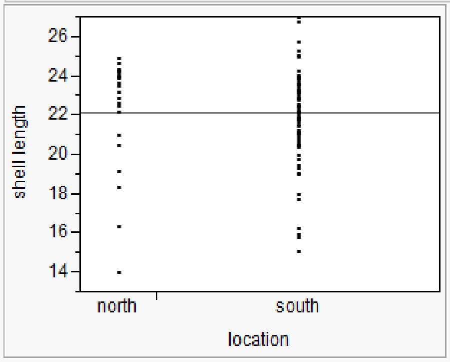
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| SCPW | NR | 7.88889 | 2.290931 | 3.44353 | 0.0006* | 0.033333 | 0.004167 | 0.083333 |
| SCPW | NCPE | 6.55556 | 2.428050 | 2.69993 | 0.0069* | 0.033333 | 0.004167 | 0.079167 |
| SCPW | NIR | 6.55556 | 2.428050 | 2.69993 | 0.0069* | 0.033333 | 0.004167 | 0.079167 |
| SCPW | SCPE | 6.11111 | 2.436112 | 2.50855 | 0.0121* | 0.029167 | 0.000000 | 0.075000 |
| SCPW | NCPW | 5.11111 | 2.464122 | 2.07421 | 0.0381* | 0.012500 | 0.000000 | 0.058333 |
| SR | NR | 4.88889 | 1.981945 | 2.46671 | 0.0136* | 0.004167 | 0.000000 | 0.012500 |
| SCPE | NR | 2.88889 | 1.634993 | 1.76691 | 0.0772 | 0.000000 | 0.000000 | 0.008333 |
| SIR | NR | 2.88889 | 1.626978 | 1.77562 | 0.0758 | 0.000000 | 0.000000 | 0.004167 |
| SR | SIR | 2.55556 | 2.241906 | 1.13990 | 0.2543 | 0.000000 | 0.000000 | 0.008333 |
| SR | NCPE | 2.22222 | 2.263666 | 0.98169 | 0.3263 | 0.000000 | 0.000000 | 0.008333 |
| SR | NIR | 2.22222 | 2.263666 | 0.98169 | 0.3263 | 0.000000 | 0.000000 | 0.008333 |
| NCPW | NCPE | 1.77778 | 2.206645 | 0.80565 | 0.4204 | 0.000000 | 0.000000 | 0.020833 |
| SR | SCPE | 1.66667 | 2.278057 | 0.73162 | 0.4644 | 0.000000 | -0.004167 | 0.004167 |
| SCPE | NCPE | 0.33333 | 2.105083 | 0.15835 | 0.8742 | 0.000000 | -0.004167 | 0.004167 |
| SCPE | NIR | 0.33333 | 2.105083 | 0.15835 | 0.8742 | 0.000000 | -0.004167 | 0.004167 |
| SR | NCPW | 0.11111 | 2.338929 | 0.04751 | 0.9621 | 0.000000 | -0.012500 | 0.004167 |
| NIR | NCPE | 0.00000 | 2.095747 | 0.00000 | 1.0000 | 0.000000 | -0.004167 | 0.004167 |
| SIR | NCPE | -0.22222 | 2.081666 | -0.10675 | 0.9150 | 0.000000 | -0.004167 | 0.004167 |
| SIR | NIR | -0.22222 | 2.081666 | -0.10675 | 0.9150 | 0.000000 | -0.004167 | 0.004167 |
| SIR | SCPE | -0.55556 | 2.097306 | -0.26489 | 0.7911 | 0.000000 | -0.004167 | 0.004167 |
| SCPE | NCPW | -1.44444 | 2.211083 | -0.65327 | 0.5136 | 0.000000 | -0.016667 | 0.004167 |
| NIR | NCPW | -1.77778 | 2.206645 | -0.80565 | 0.4204 | 0.000000 | -0.020833 | 0.000000 |
| SIR | NCPW | -1.88889 | 2.197741 | -0.85947 | 0.3901 | 0.000000 | -0.020833 | 0.000000 |
| NR | NCPE | -2.88889 | 1.632993 | -1.76908 | 0.0769 | 0.000000 | -0.004167 | 0.000000 |
| NR | NIR | -2.88889 | 1.632993 | -1.76908 | 0.0769 | 0.000000 | -0.004167 | 0.000000 |
| NR | NCPW | -3.88889 | 1.832888 | -2.12173 | 0.0339* | 0.000000 | -0.025000 | 0.000000 |
| SR | SCPW | -5.22222 | 2.462795 | -2.12045 | 0.0340* | -0.025000 | -0.070833 | 0.000000 |
| SIR | SCPW | -6.88889 | 2.415906 | -2.85147 | 0.0044* | -0.033333 | -0.079167 | -0.004167 |



**Appendix 2. JMP ANOVA results for the broad-scale population study shell length measurements by location, habitat type, and site habitat.**

### Oneway Analysis of shell length By location




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| north | 26 | 1930.50 | 1599.00 | 74.2500 | 2.070 |
| south | 96 | 5572.50 | 5904.00 | 58.0469 | -2.070 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 1930.5 | 2.06996 | 0.0385* |

#### 1-way Test, ChiSquare Approximation

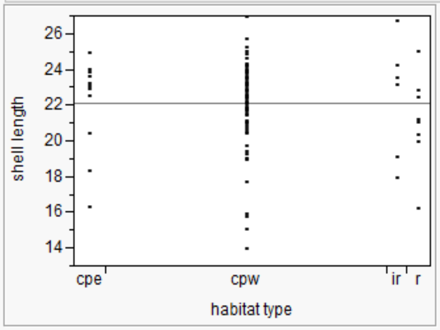
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 4.2977 | 1 | 0.0382* |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| south | north | -16.1787 | 7.815950 | -2.06996 | 0.0385* | -0.800000 | -1.50000 | 0 |

## Oneway Analysis of shell length By habitat type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| cpe | 11 | 736.000 | 676.500 | 66.9091 | 0.528 |
| cpw | 96 | 5887.00 | 5904.00 | 61.3229 | -0.103 |
| ir | 7 | 529.500 | 430.500 | 75.6429 | 1.085 |
| r | 8 | 350.500 | 492.000 | 43.8125 | -1.459 |

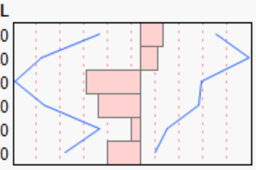
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 3.3827 | 3 | 0.3363 |

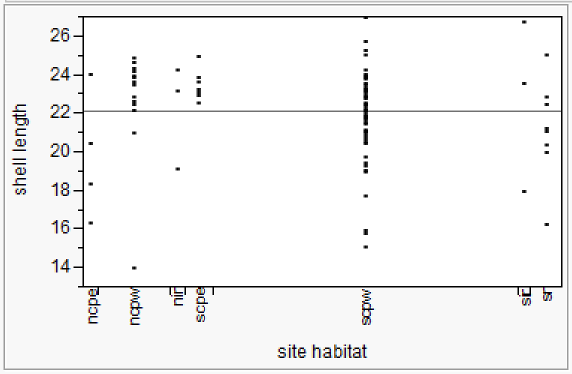
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| ir | cpw | 12.2619 | 11.69358 | 1.04860 | 0.2944 | 0.80000 | -1.40000 | 2.600000 |
| ir | cpe | 1.8701 | 2.57982 | 0.72491 | 0.4685 | 0.60000 | -3.40000 | 3.700000 |
| r | ir | -2.5446 | 2.31248 | -1.10039 | 0.2712 | -1.85000 | -4.30000 | 2.100000 |
| r | cpe | -3.3466 | 2.61479 | -1.27987 | 0.2006 | -1.45000 | -3.30000 | 2.000000 |
| cpw | cpe | -5.2183 | 9.87490 | -0.52844 | 0.5972 | -0.30000 | -1.40000 | 0.900000 |
| r | cpw | -15.5729 | 11.09713 | -1.40333 | 0.1605 | -1.10000 | -2.60000 | 0.500000 |



## Oneway Analysis of shell length By site habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| ncpe | 4 | 140.500 | 246.000 | 35.1250 | -1.510 |
| ncpw | 18 | 1478.00 | 1107.00 | 82.1111 | 2.675 |
| nir | 4 | 312.000 | 246.000 | 78.0000 | 0.942 |
| scpe | 7 | 595.500 | 430.500 | 85.0714 | 1.811 |
| scpw | 78 | 4409.00 | 4797.00 | 56.5256 | -2.067 |
| sir | 3 | 217.500 | 184.500 | 72.5000 | 0.537 |
| sr | 8 | 350.500 | 492.000 | 43.8125 | -1.459 |

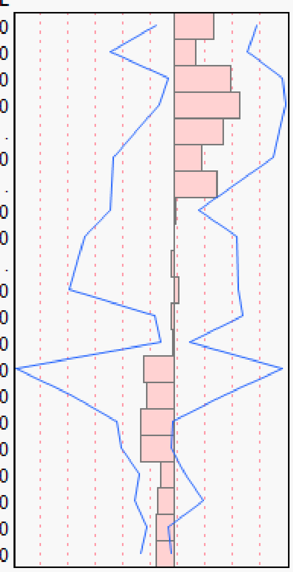
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 16.1650 | 6 | 0.0129* |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

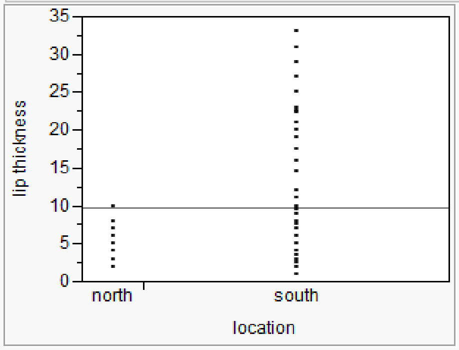
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| scpw | ncpe | 17.6090 | 12.20475 | 1.44280 | 0.1491 | 2.65000 | -1.2000 | 5.40000 |
| sir | scpw | 9.0000 | 13.83745 | 0.65041 | 0.5154 | 1.45000 | -4.3000 | 4.80000 |
| ncpw | ncpe | 5.6528 | 3.58338 | 1.57750 | 0.1147 | 3.75000 | -0.4000 | 7.10000 |
| scpe | ncpe | 2.9464 | 2.07880 | 1.41737 | 0.1564 | 4.35000 | -1.0000 | 7.30000 |
| nir | ncpe | 2.2500 | 1.72171 | 1.30684 | 0.1913 | 3.30000 | . | . |
| sr | ncpe | 1.3125 | 2.20794 | 0.59445 | 0.5522 | 1.80000 | -4.1000 | 6.50000 |
| sir | ncpe | 0.8750 | 1.64992 | 0.53033 | 0.5959 | 2.90000 | . | . |
| nir | ncpw | 0.1528 | 3.58236 | 0.04265 | 0.9660 | 0.10000 | -4.3000 | 1.60000 |
| sir | ncpw | 0.0000 | 3.86185 | 0.00000 | 1.0000 | 0.00000 | -6.0000 | 4.10000 |
| sir | nir | 0.0000 | 1.63512 | 0.00000 | 1.0000 | -0.15000 | . | . |
| sir | scpe | 0.0000 | 2.08928 | 0.00000 | 1.0000 | 0.30000 | -7.0000 | 4.20000 |
| scpe | nir | -0.1964 | 2.07407 | -0.09471 | 0.9245 | -0.15000 | -1.3000 | 4.50000 |
| scpe | ncpw | -0.5952 | 3.27201 | -0.18192 | 0.8556 | -0.10000 | -0.9000 | 1.00000 |
| sr | sir | -1.6042 | 2.24537 | -0.71443 | 0.4750 | -2.00000 | -10.5000 | 7.10000 |
| sr | nir | -2.0625 | 2.20408 | -0.93577 | 0.3494 | -1.85000 | -6.9000 | 3.30000 |
| sr | scpe | -5.2232 | 2.31455 | -2.25669 | 0.0240* | -2.20000 | -3.9000 | -0.10000 |
| sr | ncpw | -6.7708 | 3.24555 | -2.08619 | 0.0370* | -2.20000 | -3.6000 | -0.20000 |
| sr | scpw | -10.6122 | 9.26680 | -1.14518 | 0.2521 | -0.90000 | -2.4000 | 0.70000 |
| scpw | nir | -13.7981 | 12.20502 | -1.13052 | 0.2583 | -1.05000 | -2.7000 | 1.90000 |
| scpw | ncpw | -21.2650 | 7.28170 | -2.92033 | 0.0035* | -1.20000 | -1.9000 | -0.40000 |
| scpw | scpe | -22.0284 | 9.73507 | -2.26279 | 0.0236* | -1.20000 | -2.3000 | -0.20000 |



**Appendix 3. JMP ANOVA results for the broad-scale population study lip thickness measurements by location, habitat type, and site habitat.**

### Oneway Analysis of lip thickness By location




Missing Rows 27

#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| north | 16 | 674.500 | 768.000 | 42.1563 | -0.929 |
| south | 79 | 3885.50 | 3792.00 | 49.1835 | 0.929 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 674.5 | -0.92872 | 0.3530 |

#### 1-way Test, ChiSquare Approximation

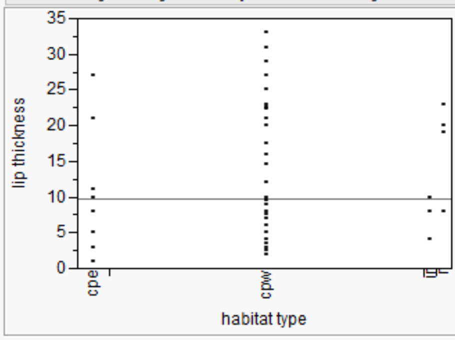
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 0.8718 | 1 | 0.3504 |

#### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| south | north | 6.989715 | 7.526149 | 0.9287240 | 0.3530 | 1.000000 | -1.00000 | 6.000000 |

## Oneway Analysis of lip thickness By habitat type




Missing Rows 27

### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| cpe | 8 | 426.000 | 384.000 | 53.2500 | 0.558 |
| cpw | 80 | 3682.00 | 3840.00 | 46.0250 | -1.614 |
| ir | 3 | 158.000 | 144.000 | 52.6667 | 0.289 |
| r | 4 | 294.000 | 192.000 | 73.5000 | 1.889 |

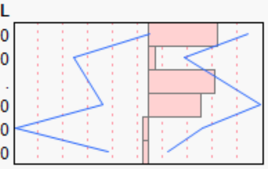
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 4.2445 | 3 | 0.2362 |

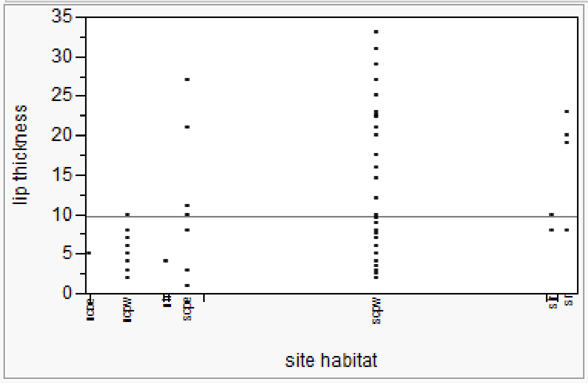
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| r | cpw | 23.7563 | 12.43859 | 1.90988 | 0.0561 | 12.0000 | 0.0000 | 17.00000 |
| ir | cpw | 6.9167 | 14.09858 | 0.49059 | 0.6237 | 1.0000 | -13.0000 | 6.00000 |
| r | ir | 2.3333 | 1.63512 | 1.42701 | 0.1536 | 11.5000 | . | . |
| r | cpe | 2.2500 | 2.20408 | 1.02084 | 0.3073 | 9.0000 | -8.0000 | 19.00000 |
| ir | cpe | -0.6875 | 2.23514 | -0.30759 | 0.7584 | -1.0000 | -23.0000 | 9.00000 |
| cpw | cpe | -6.3250 | 9.42948 | -0.67077 | 0.5024 | -1.0000 | -7.0000 | 3.00000 |



## Oneway Analysis of lip thickness By site habitat




Missing Rows 27

### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| ncpe | 1 | 43.500 | 48.000 | 43.5000 | -0.146 |
| ncpw | 14 | 596.500 | 672.000 | 42.6071 | -0.791 |
| nir | 1 | 34.500 | 48.000 | 34.5000 | -0.476 |
| scpe | 7 | 382.500 | 336.000 | 54.6429 | 0.658 |
| scpw | 66 | 3085.50 | 3168.00 | 46.7500 | -0.665 |
| sir | 2 | 123.500 | 96.000 | 61.7500 | 0.703 |
| sr | 4 | 294.000 | 192.000 | 73.5000 | 1.889 |

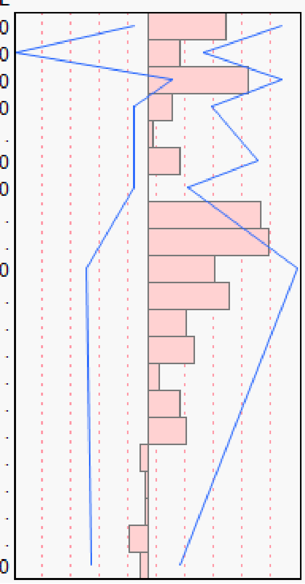
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 5.3086 | 6 | 0.5049 |

## Nonparametric Comparisons For Each Pair Using Wilcoxon Method

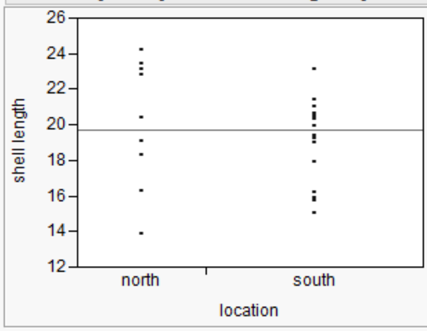
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| sr | scpw | 17.1023 | 10.42623 | 1.64031 | 0.1009 | 10.0000 | -2.0000 | 17.00000 |
| sir | scpw | 8.7576 | 14.11390 | 0.62049 | 0.5349 | 4.0000 | -17.0000 | 7.00000 |
| sr | ncpw | 8.1964 | 2.99842 | 2.73358 | 0.0063* | 13.0000 | 3.0000 | 17.00000 |
| sir | ncpw | 6.2857 | 3.54831 | 1.77147 | 0.0765 | 3.0000 | -2.0000 | 8.00000 |
| scpw | nir | 4.5682 | 19.50949 | 0.23415 | 0.8149 | 0.5000 | . | . |
| scpe | ncpw | 4.1786 | 2.85357 | 1.46433 | 0.1431 | 4.0000 | -2.0000 | 14.00000 |
| scpw | ncpw | 1.9481 | 6.80095 | 0.28644 | 0.7745 | 0.0000 | -2.0000 | 5.00000 |
| sr | ncpe | 1.8750 | 1.76777 | 1.06066 | 0.2888 | 14.5000 | . | . |
| sr | nir | 1.8750 | 1.76777 | 1.06066 | 0.2888 | 15.5000 | . | . |
| sr | scpe | 1.5714 | 2.07407 | 0.75765 | 0.4487 | 8.5000 | -8.0000 | 19.00000 |
| sr | sir | 1.5000 | 1.59687 | 0.93934 | 0.3476 | 10.5000 | . | . |
| scpe | ncpe | 1.1429 | 2.61861 | 0.43644 | 0.6625 | 5.0000 | . | . |
| scpe | nir | 1.1429 | 2.61861 | 0.43644 | 0.6625 | 6.0000 | . | . |
| ncpw | ncpe | 1.0714 | 4.56249 | 0.23483 | 0.8143 | 1.5000 | . | . |
| sir | ncpe | 0.7500 | 1.22474 | 0.61237 | 0.5403 | 4.0000 | . | . |
| sir | nir | 0.7500 | 1.22474 | 0.61237 | 0.5403 | 5.0000 | . | . |
| nir | ncpe | 0.0000 | 1.00000 | 0.00000 | 1.0000 | -1.0000 | . | . |
| sir | scpe | -0.3214 | 2.17740 | -0.14762 | 0.8826 | -0.5000 | . | . |
| scpw | ncpe | -0.5076 | 19.51974 | -0.02600 | 0.9793 | -0.5000 | . | . |
| nir | ncpw | -3.2143 | 4.54148 | -0.70776 | 0.4791 | -2.5000 | . | . |
| scpw | scpe | -4.1872 | 8.39011 | -0.49907 | 0.6177 | -1.0000 | -7.5000 | 4.00000 |



**Appendix 4. JMP ANOVA results for the broad-scale population study juvenile shell length measurements by location, habitat type, and site habitat.**

### Oneway Analysis of shell length By location




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| north | 10 | 163.500 | 140.000 | 16.3500 | 1.156 |
| south | 17 | 214.500 | 238.000 | 12.6176 | -1.156 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 163.5 | 1.15553 | 0.2479 |

#### 1-way Test, ChiSquare Approximation

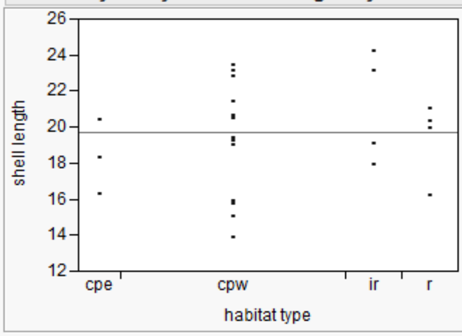
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 1.3939 | 1 | 0.2377 |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| south | north | -3.65294 | 3.161276 | -1.15553 | 0.2479 | -2.00000 | -3.70000 | 1.500000 |

## Oneway Analysis of shell length By habitat type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| cpe | 3 | 29.000 | 42.000 | 9.6667 | -0.965 |
| cpw | 16 | 230.500 | 224.000 | 14.4063 | 0.296 |
| ir | 4 | 67.500 | 56.000 | 16.8750 | 0.751 |
| r | 4 | 51.000 | 56.000 | 12.7500 | -0.307 |

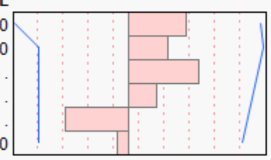
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 1.5620 | 3 | 0.6680 |

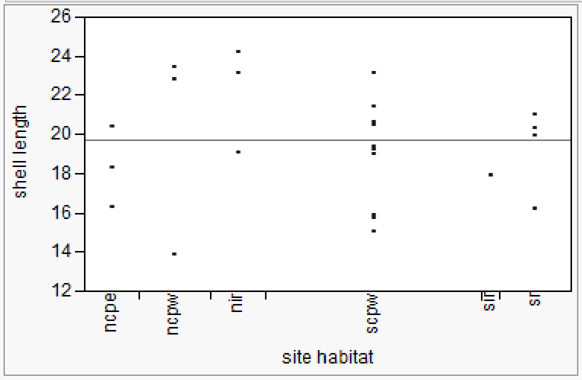
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| cpw | cpe | 3.36458 | 3.535779 | 0.951582 | 0.3413 | 2.25000 | -4.40000 | 5.100000 |
| ir | cpw | 1.87500 | 3.302212 | 0.567801 | 0.5702 | 1.55000 | -3.50000 | 5.200000 |
| ir | cpe | 1.45833 | 1.649916 | 0.883883 | 0.3768 | 2.75000 | . | . |
| r | cpe | 0.29167 | 1.649916 | 0.176777 | 0.8597 | 1.10000 | . | . |
| r | ir | -0.75000 | 1.732051 | -0.433013 | 0.6650 | -2.45000 | . | . |
| r | cpw | -1.09375 | 3.303457 | -0.331093 | 0.7406 | -0.40000 | -3.50000 | 4.400000 |



## Oneway Analysis of shell length By site habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| ncpe | 3 | 29.000 | 42.000 | 9.6667 | -0.965 |
| ncpw | 4 | 74.000 | 56.000 | 18.5000 | 1.195 |
| nir | 3 | 60.500 | 42.000 | 20.1667 | 1.390 |
| scpw | 12 | 156.500 | 168.000 | 13.0417 | -0.537 |
| sir | 1 | 7.000 | 14.000 | 7.0000 | -0.835 |
| sr | 4 | 51.000 | 56.000 | 12.7500 | -0.307 |

### 1-way Test, ChiSquare Approximation

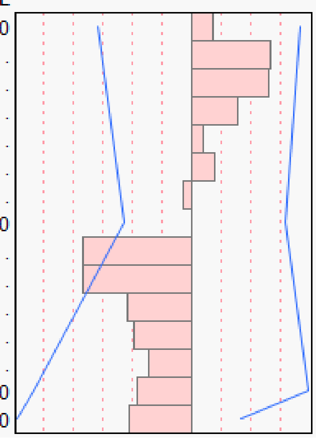
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 5.0488 | 5 | 0.4100 |

Small sample sizes. Refer to statistical tables for tests, rather than large-sample approximations.

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

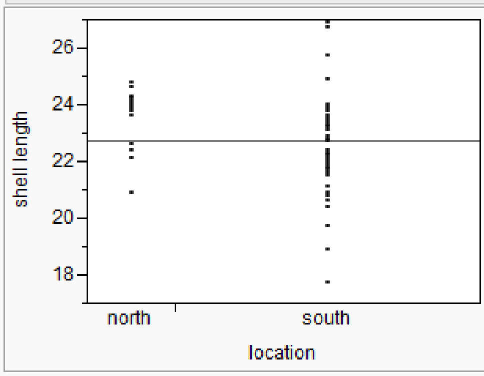
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| scpw | ncpe | 2.29167 | 2.881592 | 0.79528 | 0.4265 | 1.00000 | -4.50000 | 5.100000 |
| nir | ncpe | 2.00000 | 1.527525 | 1.30931 | 0.1904 | 3.80000 | . | . |
| ncpw | ncpe | 1.45833 | 1.635118 | 0.89188 | 0.3725 | 3.75000 | . | . |
| sr | sir | 0.62500 | 1.767767 | 0.35355 | 0.7237 | 2.20000 | . | . |
| nir | ncpw | 0.29167 | 1.635118 | 0.17838 | 0.8584 | 0.55000 | . | . |
| sr | ncpe | 0.29167 | 1.649916 | 0.17678 | 0.8597 | 1.10000 | . | . |
| sir | ncpe | 0.00000 | 1.490712 | 0.00000 | 1.0000 | -0.40000 | . | . |
| sr | scpw | 0.00000 | 2.744692 | 0.00000 | 1.0000 | 0.05000 | -3.20000 | 4.400000 |
| sir | ncpw | -0.62500 | 1.723006 | -0.36274 | 0.7168 | -5.20000 | . | . |
| sir | nir | -1.33333 | 1.490712 | -0.89443 | 0.3711 | -5.20000 | . | . |
| sr | nir | -1.45833 | 1.649916 | -0.88388 | 0.3768 | -3.05000 | . | . |
| sr | ncpw | -1.75000 | 1.721710 | -1.01643 | 0.3094 | -2.70000 | . | . |
| sir | scpw | -2.70833 | 4.042311 | -0.67000 | 0.5029 | -2.05000 | . | . |
| scpw | ncpw | -3.50000 | 2.742667 | -1.27613 | 0.2019 | -2.55000 | -7.50000 | 5.500000 |
| scpw | nir | -3.75000 | 2.879009 | -1.30253 | 0.1927 | -3.00000 | -8.30000 | 2.300000 |



**Appendix 5. JMP ANOVA results for the broad-scale population study sub-adult shell length and lip thickness measurements by location, habitat type, and site habitat.**

### Oneway Analysis of shell length By location




#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| north | 16 | 827.500 | 584.000 | 51.7188 | 3.293 |
| south | 56 | 1800.50 | 2044.00 | 32.1518 | -3.293 |

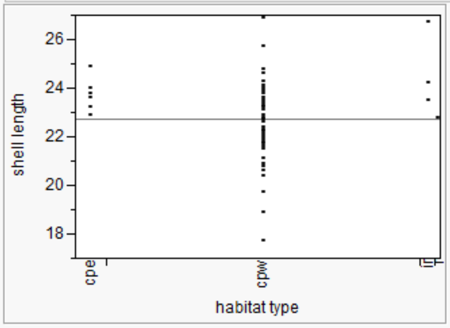
#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 827.5 | 3.29331 | 0.0010* |

#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 10.8906 | 1 | 0.0010* |

## Oneway Analysis of shell length By habitat type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| cpe | 6 | 322.500 | 219.000 | 53.7500 | 2.100 |
| cpw | 62 | 2083.00 | 2263.00 | 33.5968 | -2.924 |
| ir | 3 | 185.500 | 109.500 | 61.8333 | 2.129 |
| r | 1 | 37.000 | 36.500 | 37.0000 | 0.000 |

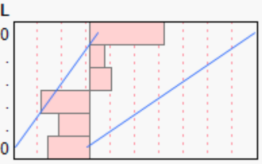
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 9.6768 | 3 | 0.0215* |

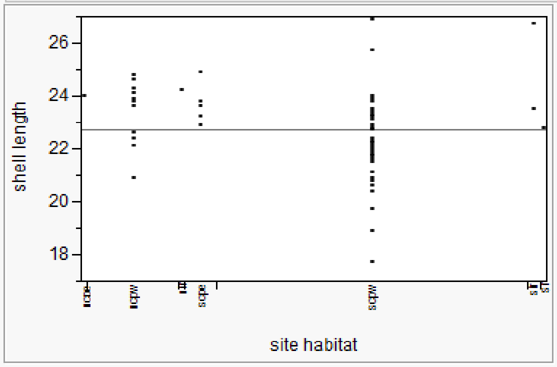
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| ir | cpw | 24.4624 | 11.17061 | 2.18989 | 0.0285* | 2.10000 | 0.20000 | 4.60000 |
| r | cpw | 4.5726 | 18.46489 | 0.24764 | 0.8044 | 0.40000 | . | . |
| ir | cpe | 1.7500 | 1.93649 | 0.90370 | 0.3662 | 0.60000 | . | . |
| r | ir | -1.3333 | 1.49071 | -0.89443 | 0.3711 | -1.40000 | . | . |
| r | cpe | -2.9167 | 2.33333 | -1.25000 | 0.2113 | -0.90000 | . | . |
| cpw | cpe | -19.0108 | 8.44869 | -2.25014 | 0.0244* | -1.20000 | -2.10000 | -0.10000 |



## Oneway Analysis of shell length By site habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| ncpe | 1 | 62.500 | 36.500 | 62.5000 | 1.228 |
| ncpw | 14 | 700.000 | 511.000 | 50.0000 | 2.684 |
| nir | 1 | 65.000 | 36.500 | 65.0000 | 1.348 |
| scpe | 5 | 260.000 | 182.500 | 52.0000 | 1.707 |
| scpw | 48 | 1383.00 | 1752.00 | 28.8125 | -4.404 |
| sir | 2 | 120.500 | 73.000 | 60.2500 | 1.611 |
| sr | 1 | 37.000 | 36.500 | 37.0000 | 0.000 |

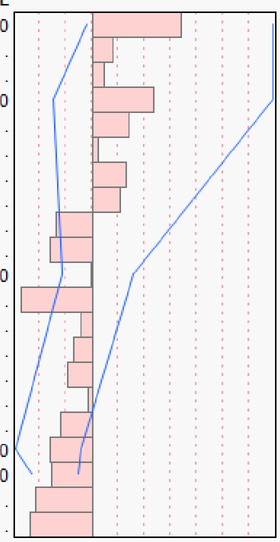
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 21.0428 | 6 | 0.0018* |

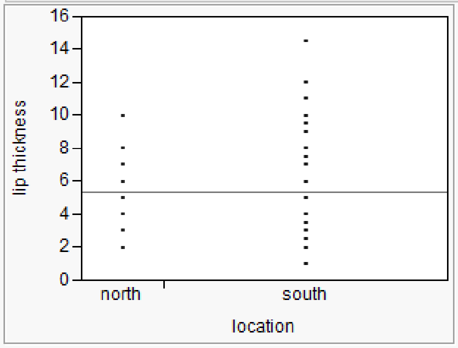
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| sir | scpw | 20.8333 | 10.51375 | 1.98153 | 0.0475* | 2.90000 | -0.20000 | 5.80000 |
| sr | scpw | 7.6563 | 14.42645 | 0.53071 | 0.5956 | 0.65000 | . | . |
| nir | ncpw | 3.7500 | 4.60839 | 0.81373 | 0.4158 | 0.35000 | . | . |
| sir | ncpw | 2.0000 | 3.58569 | 0.55777 | 0.5770 | 2.00000 | -1.30000 | 5.80000 |
| sir | scpe | 1.0500 | 1.80739 | 0.58095 | 0.5613 | 1.20000 | . | . |
| nir | ncpe | 0.0000 | 1.00000 | 0.00000 | 1.0000 | 0.20000 | . | . |
| sir | ncpe | 0.0000 | 1.22474 | 0.00000 | 1.0000 | 1.10000 | . | . |
| sir | nir | 0.0000 | 1.22474 | 0.00000 | 1.0000 | 0.90000 | . | . |
| sr | ncpe | 0.0000 | 1.00000 | 0.00000 | 1.0000 | -1.20000 | . | . |
| sr | nir | 0.0000 | 1.00000 | 0.00000 | 1.0000 | -1.40000 | . | . |
| scpe | ncpw | -0.2714 | 2.92017 | -0.09295 | 0.9259 | -0.05000 | -1.00000 | 1.30000 |
| sr | sir | -0.7500 | 1.22474 | -0.61237 | 0.5403 | -2.30000 | . | . |
| scpe | ncpe | -1.2000 | 2.04939 | -0.58554 | 0.5582 | -0.40000 | . | . |
| scpe | nir | -1.2000 | 2.04939 | -0.58554 | 0.5582 | -0.60000 | . | . |
| sr | scpe | -2.4000 | 2.04939 | -1.17108 | 0.2416 | -0.80000 | . | . |
| ncpw | ncpe | -2.6786 | 4.60839 | -0.58124 | 0.5611 | -0.15000 | . | . |
| sr | ncpw | -2.6786 | 4.60839 | -0.58124 | 0.5611 | -1.05000 | . | . |
| scpw | scpe | -17.8875 | 7.25264 | -2.46634 | 0.0137* | -1.40000 | -2.50000 | -0.40000 |
| scpw | ncpw | -17.9911 | 5.47635 | -3.28523 | 0.0010* | -1.35000 | -2.00000 | -0.50000 |
| scpw | ncpe | -21.4375 | 14.42718 | -1.48591 | 0.1373 | -1.85000 | . | . |
| scpw | nir | -21.9479 | 14.42755 | -1.52125 | 0.1282 | -2.05000 | . | . |



## Oneway Analysis of lip thickness By location




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| north | 16 | 674.500 | 584.000 | 42.1563 | 1.231 |
| south | 56 | 1953.50 | 2044.00 | 34.8839 | -1.231 |

### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 674.5 | 1.23075 | 0.2184 |

### 1-way Test, ChiSquare Approximation

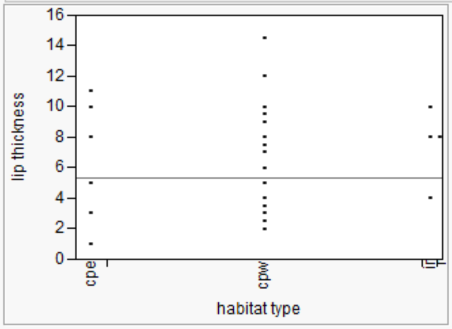
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 1.5316 | 1 | 0.2159 |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| south | north | -7.23214 | 5.876207 | -1.23075 | 0.2184 | -1.00000 | -2.00000 | 1.000000 |

## Oneway Analysis of lip thickness By habitat type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| cpe | 6 | 256.000 | 219.000 | 42.6667 | 0.751 |
| cpw | 62 | 2157.00 | 2263.00 | 34.7903 | -1.734 |
| ir | 3 | 158.000 | 109.500 | 52.6667 | 1.366 |
| r | 1 | 57.000 | 36.500 | 57.0000 | 0.972 |

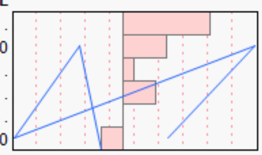
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 3.7554 | 3 | 0.2891 |

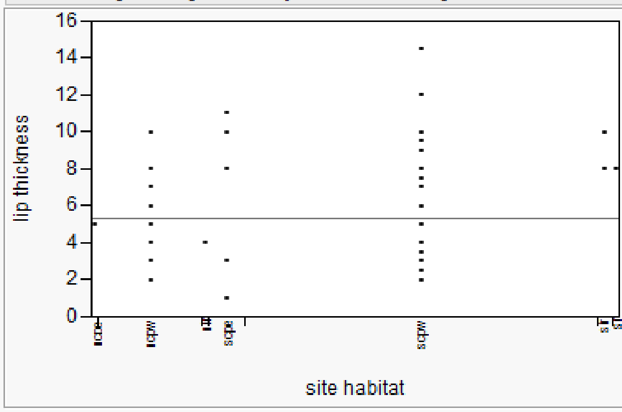
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| r | cpw | 19.8145 | 18.27351 | 1.08433 | 0.2782 | 4.00000 | . | . |
| ir | cpw | 16.4247 | 11.05255 | 1.48606 | 0.1373 | 2.00000 | -2.00000 | 6.000000 |
| ir | cpe | 0.2500 | 1.92029 | 0.13019 | 0.8964 | 0.50000 | . | . |
| r | cpe | 0.0000 | 2.31241 | 0.00000 | 1.0000 | 1.50000 | . | . |
| r | ir | 0.0000 | 1.41421 | 0.00000 | 1.0000 | 0.00000 | . | . |
| cpw | cpe | -6.9462 | 8.37018 | -0.82988 | 0.4066 | -1.00000 | -5.00000 | 2.000000 |



## Oneway Analysis of lip thickness By site habitat




## Oneway Analysis of lip thickness By site habitat

### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| ncpe | 1 | 43.500 | 36.500 | 43.5000 | 0.316 |
| ncpw | 14 | 596.500 | 511.000 | 42.6071 | 1.221 |
| nir | 1 | 34.500 | 36.500 | 34.5000 | -0.073 |
| scpe | 5 | 212.500 | 182.500 | 42.5000 | 0.660 |
| scpw | 48 | 1560.50 | 1752.00 | 32.5104 | -2.304 |
| sir | 2 | 123.500 | 73.000 | 61.7500 | 1.730 |
| sr | 1 | 57.000 | 36.500 | 57.0000 | 0.972 |

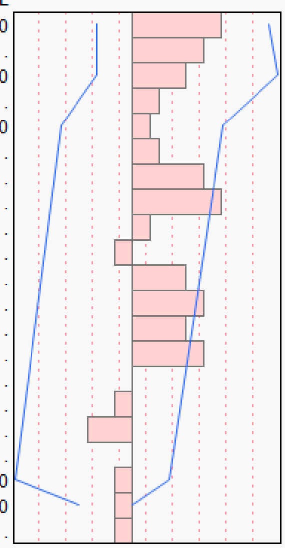
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 7.4808 | 6 | 0.2787 |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

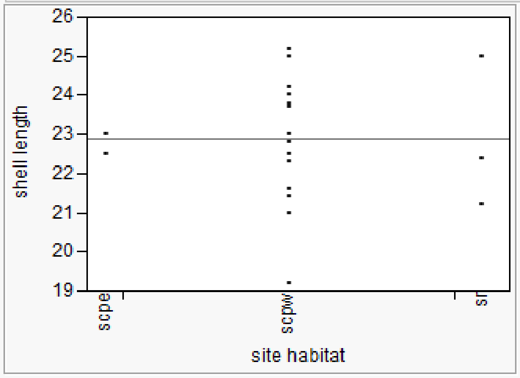
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| sir | scpw | 18.2292 | 10.37534 | 1.75697 | 0.0789 | 5.00000 | -2.00000 | 7.500000 |
| sr | scpw | 14.8021 | 14.22753 | 1.04038 | 0.2982 | 4.00000 | . | . |
| sir | ncpw | 6.2857 | 3.54831 | 1.77147 | 0.0765 | 3.00000 | -2.00000 | 8.000000 |
| sr | ncpw | 4.8214 | 4.55410 | 1.05870 | 0.2897 | 1.50000 | . | . |
| scpe | ncpw | 1.4929 | 2.90593 | 0.51373 | 0.6074 | 1.00000 | -4.00000 | 5.000000 |
| ncpw | ncpe | 1.0714 | 4.56249 | 0.23483 | 0.8143 | 1.50000 | . | . |
| sir | ncpe | 0.7500 | 1.22474 | 0.61237 | 0.5403 | 4.00000 | . | . |
| sir | nir | 0.7500 | 1.22474 | 0.61237 | 0.5403 | 5.00000 | . | . |
| sir | scpe | 0.3500 | 1.77482 | 0.19720 | 0.8437 | 1.00000 | . | . |
| nir | ncpe | 0.0000 | 1.00000 | 0.00000 | 1.0000 | -1.00000 | . | . |
| scpe | ncpe | 0.0000 | 2.04939 | 0.00000 | 1.0000 | 3.00000 | . | . |
| scpe | nir | 0.0000 | 2.04939 | 0.00000 | 1.0000 | 4.00000 | . | . |
| sr | ncpe | 0.0000 | 1.00000 | 0.00000 | 1.0000 | 3.00000 | . | . |
| sr | nir | 0.0000 | 1.00000 | 0.00000 | 1.0000 | 4.00000 | . | . |
| sr | scpe | 0.0000 | 2.01990 | 0.00000 | 1.0000 | 0.00000 | . | . |
| sr | sir | 0.0000 | 1.06066 | 0.00000 | 1.0000 | -1.00000 | . | . |
| nir | ncpw | -3.2143 | 4.54148 | -0.70776 | 0.4791 | -2.50000 | . | . |
| scpw | nir | -3.5729 | 14.20809 | -0.25147 | 0.8015 | 0.00000 | . | . |
| scpw | scpe | -5.1896 | 7.15997 | -0.72481 | 0.4686 | -1.00000 | -6.50000 | 2.000000 |
| scpw | ncpw | -9.4568 | 5.41727 | -1.74568 | 0.0809 | -1.00000 | -3.00000 | 0.000000 |
| scpw | ncpe | -9.6979 | 14.22753 | -0.68163 | 0.4955 | -1.00000 | . | . |



**Appendix 6. JMP ANOVA results for the broad-scale study population adult shell length and lip thickness measurements by site habitat.**

### Oneway Analysis of shell length By site habitat




#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| scpe | 2 | 22.000 | 24.000 | 11.0000 | -0.164 |
| scpw | 18 | 220.500 | 216.000 | 12.2500 | 0.299 |
| sr | 3 | 33.500 | 36.000 | 11.1667 | -0.183 |

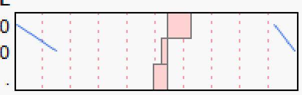
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 0.1137 | 2 | 0.9447 |

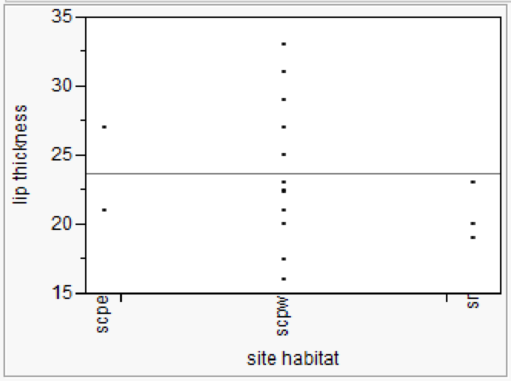
#### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| scpw | scpe | 1.38889 | 4.396304 | 0.315922 | 0.7521 | 0.600000 | -3.80000 | 2.700000 |
| sr | scpw | -0.38889 | 3.860591 | -0.100733 | 0.9198 | -0.150000 | -2.80000 | 3.200000 |
| sr | scpe | -0.41667 | 1.443376 | -0.288675 | 0.7728 | -0.350000 | . | . |



## Oneway Analysis of lip thickness By site habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| scpe | 2 | 26.000 | 24.000 | 13.0000 | 0.164 |
| scpw | 18 | 229.000 | 216.000 | 12.7222 | 0.935 |
| sr | 3 | 21.000 | 36.000 | 7.0000 | -1.329 |

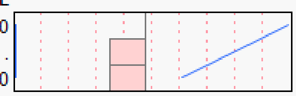
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 1.8930 | 2 | 0.3881 |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

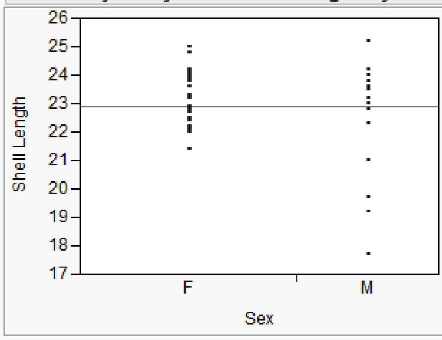
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| scpw | scpe | 0.00000 | 4.392977 | 0.00000 | 1.0000 | 0.00000 | -11.0000 | 12.00000 |
| sr | scpe | -1.25000 | 1.443376 | -0.86603 | 0.3865 | -3.00000 | . | . |
| sr | scpw | -4.86111 | 3.851767 | -1.26205 | 0.2069 | -3.00000 | -11.0000 | 3.00000 |



**Appendix 7. JMP ANOVA results for the broad-scale population study sub-adult and adult shell length and lip thickness measurements by sex.**

### Oneway Analysis of Shell Length By Sex




#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| F | 26 | 600.500 | 572.000 | 23.0962 | 0.696 |
| M | 17 | 345.500 | 374.000 | 20.3235 | -0.696 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 345.5 | -0.69634 | 0.4862 |

#### 1-way Test, ChiSquare Approximation

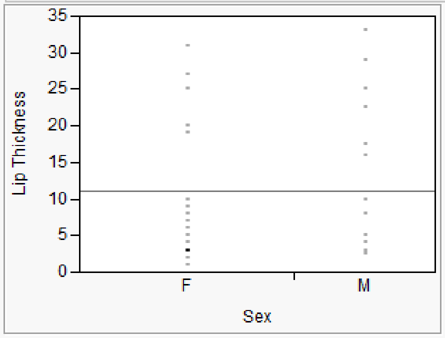
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 0.5024 | 1 | 0.4785 |

#### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| M | F | -2.72398 | 3.911868 | -0.696338 | 0.4862 | -0.200000 | -1.20000 | 0.4000000 |

## Oneway Analysis of Lip Thickness By Sex




Missing Rows 12

### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| F | 26 | 497.500 | 572.000 | 19.1346 | -1.846 |
| M | 17 | 448.500 | 374.000 | 26.3824 | 1.846 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 448.5 | 1.84585 | 0.0649 |

#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 3.4534 | 1 | 0.0631 |

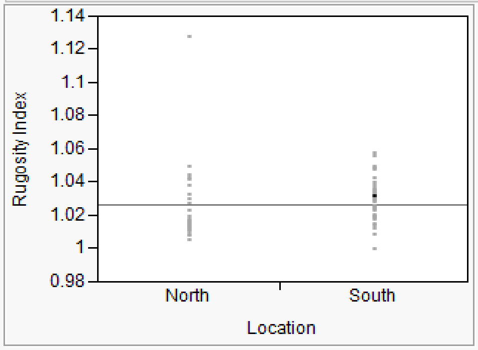
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| M | F | 7.199095 | 3.900156 | 1.845848 | 0.0649 | 4.000000 | 0 | 13.00000 |

**Appendix 8. JMP ANOVA results for rugosity index by location, habitat type, and site habitat.**

### Oneway Analysis of Rugosity Index By Location




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| North | 35 | 1004.50 | 1260.00 | 28.7000 | -2.934 |
| South | 36 | 1551.50 | 1296.00 | 43.0972 | 2.934 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 1004.5 | -2.93401 | 0.0033* |

#### 1-way Test, ChiSquare Approximation

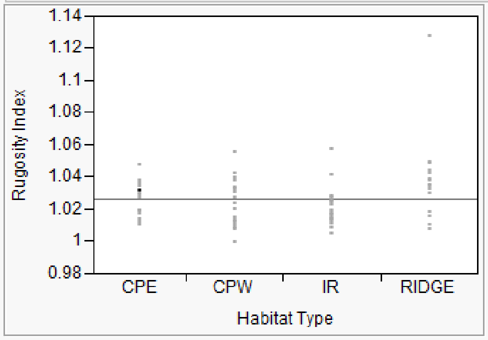
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 8.6422 | 1 | 0.0033* |

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| South | North | 14.36905 | 4.897411 | 2.934009 | 0.0033* | 0.0093116 | 0.0034356 | 0.0165013 |

## Oneway Analysis of Rugosity Index By Habitat Type




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| CPE | 17 | 598.000 | 612.000 | 35.1765 | -0.182 |
| CPW | 18 | 584.000 | 648.000 | 32.4444 | -0.840 |
| IR | 18 | 528.500 | 648.000 | 29.3611 | -1.574 |
| RIDGE | 18 | 845.500 | 648.000 | 46.9722 | 2.605 |

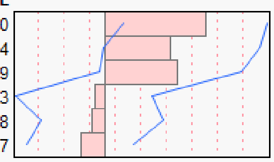
#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 7.5167 | 3 | 0.0571 |

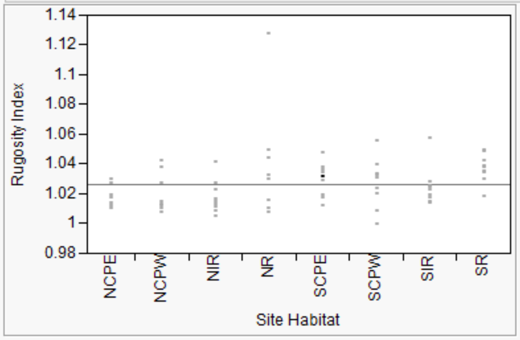
### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| RIDGE | IR | 8.72222 | 3.510754 | 2.48443 | 0.0130* | 0.015044 | 0.002646 | 0.0236920 |
| RIDGE | CPW | 6.72222 | 3.510076 | 1.91512 | 0.0555 | 0.009662 | -0.000181 | 0.0226784 |
| RIDGE | CPE | 6.51961 | 3.462117 | 1.88313 | 0.0597 | 0.010757 | -0.000864 | 0.0199419 |
| IR | CPW | -0.88889 | 3.509850 | -0.25326 | 0.8001 | -0.001301 | -0.013027 | 0.0068713 |
| CPW | CPE | -1.25817 | 3.461388 | -0.36349 | 0.7162 | -0.001736 | -0.009392 | 0.0086038 |
| IR | CPE | -3.60294 | 3.461631 | -1.04082 | 0.2980 | -0.003436 | -0.011504 | 0.0042837 |



## Oneway Analysis of Rugosity Index By Site Habitat




### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| NCPE | 8 | 206.500 | 288.000 | 25.8125 | -1.474 |
| NCPW | 9 | 232.000 | 324.000 | 25.7778 | -1.582 |
| NIR | 9 | 212.500 | 324.000 | 23.6111 | -1.919 |
| NR | 9 | 353.500 | 324.000 | 39.2778 | 0.501 |
| SCPE | 9 | 391.500 | 324.000 | 43.5000 | 1.158 |
| SCPW | 9 | 352.000 | 324.000 | 39.1111 | 0.475 |
| SIR | 9 | 316.000 | 324.000 | 35.1111 | -0.130 |
| SR | 9 | 492.000 | 324.000 | 54.6667 | 2.896 |

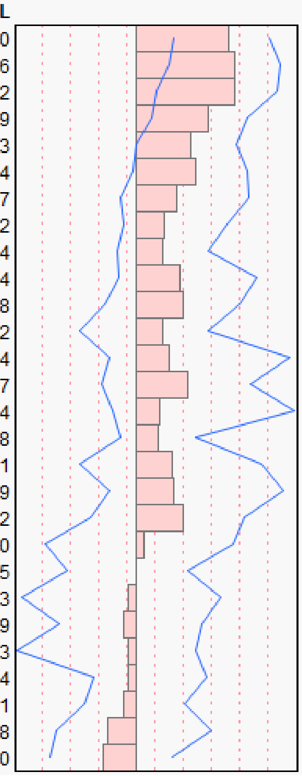
### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 16.4111 | 7 | 0.0216* |

## Nonparametric Comparisons For Each Pair Using Wilcoxon Method

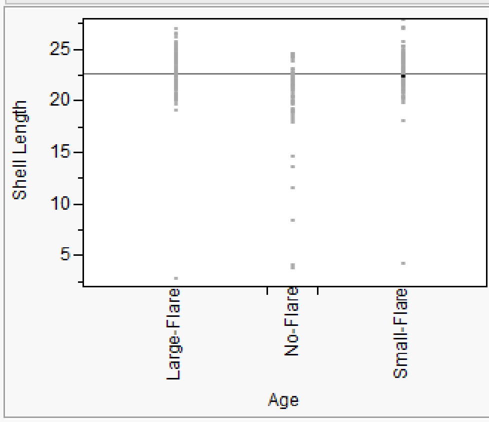
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| SR | NCPE | 7.55556 | 2.450730 | 3.08298 | 0.0020* | 0.020461 | 0.008019 | 0.0288770 |
| SR | NIR | 7.11111 | 2.516611 | 2.82567 | 0.0047* | 0.021825 | 0.007085 | 0.0314386 |
| SR | NCPW | 6.11111 | 2.514013 | 2.43082 | 0.0151* | 0.021825 | 0.004328 | 0.0305862 |
| SR | SIR | 5.77778 | 2.516611 | 2.29586 | 0.0217* | 0.015807 | 0.003441 | 0.0241859 |
| SCPE | NCPE | 5.19444 | 2.446210 | 2.12347 | 0.0337* | 0.012210 | 0.000000 | 0.0217133 |
| SCPE | NIR | 5.11111 | 2.516611 | 2.03095 | 0.0423* | 0.013071 | -0.000854 | 0.0241344 |
| SCPE | NCPW | 4.11111 | 2.510110 | 1.63782 | 0.1015 | 0.009094 | -0.003580 | 0.0243817 |
| SR | SCPE | 4.00000 | 2.514013 | 1.59108 | 0.1116 | 0.006248 | -0.002687 | 0.0197662 |
| SIR | NIR | 3.77778 | 2.514013 | 1.50269 | 0.1329 | 0.006017 | -0.004342 | 0.0156194 |
| SR | SCPW | 3.77778 | 2.516611 | 1.50114 | 0.1333 | 0.009630 | -0.003946 | 0.0260794 |
| SCPW | NCPE | 3.65972 | 2.452235 | 1.49240 | 0.1356 | 0.010342 | -0.006989 | 0.0223718 |
| SIR | NCPW | 3.44444 | 2.514013 | 1.37010 | 0.1707 | 0.006017 | -0.012421 | 0.0154612 |
| NR | NIR | 3.33333 | 2.515313 | 1.32522 | 0.1851 | 0.007284 | -0.005987 | 0.0334344 |
| SCPW | NIR | 3.22222 | 2.515313 | 1.28104 | 0.2002 | 0.011233 | -0.007685 | 0.0249507 |
| NR | NCPW | 3.11111 | 2.511412 | 1.23879 | 0.2154 | 0.005305 | -0.005360 | 0.0342854 |
| SIR | NCPE | 2.71528 | 2.444701 | 1.11068 | 0.2667 | 0.004743 | -0.003436 | 0.0129608 |
| SR | NR | 2.66667 | 2.512713 | 1.06127 | 0.2886 | 0.008019 | -0.012231 | 0.0271621 |
| NR | NCPE | 2.24306 | 2.447717 | 0.91639 | 0.3595 | 0.008336 | -0.005957 | 0.0320019 |
| SCPW | NCPW | 2.22222 | 2.515313 | 0.88348 | 0.3770 | 0.010307 | -0.009869 | 0.0233712 |
| SCPE | NR | 0.66667 | 2.515313 | 0.26504 | 0.7910 | 0.001771 | -0.019792 | 0.0210410 |
| NIR | NCPW | -0.11111 | 2.511412 | -0.04424 | 0.9647 | 0.000000 | -0.015174 | 0.0112135 |
| SCPW | NR | -0.11111 | 2.514013 | -0.04420 | 0.9647 | -0.001698 | -0.025060 | 0.0183633 |
| SCPW | SCPE | -0.66667 | 2.516611 | -0.26491 | 0.7911 | -0.002678 | -0.016949 | 0.0143969 |
| SIR | NR | -0.88889 | 2.515313 | -0.35339 | 0.7238 | -0.001765 | -0.025933 | 0.0128823 |
| NCPW | NCPE | -1.06250 | 2.443191 | -0.43488 | 0.6636 | -0.001709 | -0.009392 | 0.0151744 |
| NIR | NCPE | -1.41667 | 2.450730 | -0.57806 | 0.5632 | -0.002570 | -0.011309 | 0.0104481 |
| SIR | SCPW | -1.77778 | 2.516611 | -0.70642 | 0.4799 | -0.006038 | -0.017414 | 0.0163618 |
| SIR | SCPE | -3.00000 | 2.515313 | -1.19269 | 0.2330 | -0.007049 | -0.018843 | 0.0078160 |



# Appendix 9. JMP ANOVA results for aggregation population study shell length and lip thickness measurements by age class.

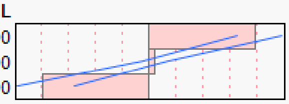
## Oneway Analysis of Shell Length By Age



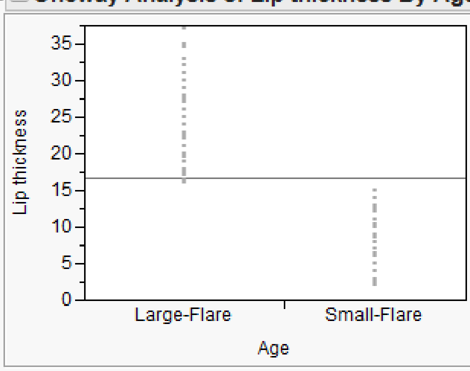

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| Small-Flare | No-Flare | 88.3256 | 11.56798 | 7.63535 | <.0001* | 1.70000 | 1.40000 | 2.10000 |
| Small-Flare | Large-Flare | 9.1084 | 12.39051 | 0.73511 | 0.4623 | 0.10000 | -0.10000 | 0.30000 |
| No-Flare | Large-Flare | -84.8841 | 12.29344 | -6.90483 | <.0001* | -1.70000 | -2.10000 | -1.20000 |



## Oneway Analysis of Lip thickness By Age

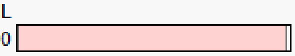



Missing Rows 66

### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

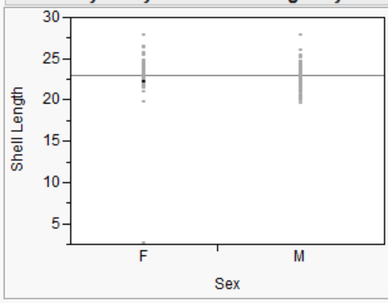
| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| Small-Flare | Large-Flare | -229.496 | 12.38669 | -18.5276 | <.0001* | -14.0000 | -14.0000 | -13.0000 |



**Appendix 10. JMP ANOVA results for aggregation population study sub-adult and adult shell length and lip thickness by sex.**

### Oneway Analysis of Shell Length By Sex




#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| F | 106 | 13915.5 | 12084.0 | 131.278 | 3.711 |
| M | 121 | 11962.5 | 13794.0 | 98.864 | -3.711 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 13915.5 | 3.71069 | 0.0002* |

#### 1-way Test, ChiSquare Approximation

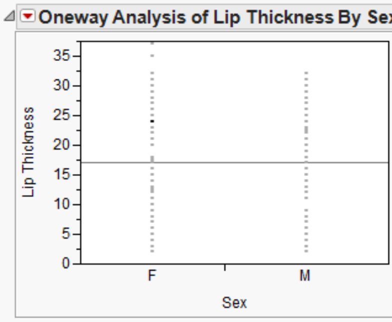
| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 13.7767 | 1 | 0.0002* |

#### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| M | F | -32.4058 | 8.733097 | -3.71069 | 0.0002* | -0.600000 | -1.00000 | -0.300000 |

### Oneway Analysis of Lip Thickness By Sex




#### Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| F | 106 | 10288.0 | 12084.0 | 97.057 | -3.641 |
| M | 121 | 15590.0 | 13794.0 | 128.843 | 3.641 |

#### 2-Sample Test, Normal Approximation

| S | Z | Prob>\|Z\| |
|---|---|---|
| 10288 | -3.64112 | 0.0003* |

#### 1-way Test, ChiSquare Approximation

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 13.2651 | 1 | 0.0003* |

#### Nonparametric Comparisons For Each Pair Using Wilcoxon Method

| q* | Alpha |
|---|---|
| 1.95996 | 0.05 |

| Level | - Level | Score Mean Difference | Std Err Dif | Z | p-Value | Hodges-Lehmann | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|---|
| M | F | 31.77752 | 8.727407 | 3.641118 | 0.0003* | 4.000000 | 2.000000 | 6.000000 |